Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 204 OCTOBER, 1927 No. 4

THE SEARCH FOR THE SOURCE OF STELLAR ENERGY.*

BY

JOHN QUINCY STEWART, Ph.D.

Assistant Professor of Astronomical Physics, Princeton University.

THE meaning of the term "energy," as used in physics, may be taken for granted nowadays. The presentation of a proper definition would involve a considerable technical discussion.

The energy radiation from the sun and stars is of the electromagnetic type. The solar energy, for example, which reaches the earth, has crossed the ninety-three million miles of empty space between sun and earth in the form of radiant heat, light, and ultra-violet radiation. Its speed of travel outward from the sun presumably is that of light, or 186,285 miles per second.

The doctrine of the conservation of energy, nearly a century old now, and still (in a generalized form) adhered to by almost all physicists, raises the problem which is the theme of the present discussion. If energy is not created out of nothing, then the great flood of energy which a star is continuously pouring out from its surface must have its source in an enormous reservoir within the star.

I. THE SUN'S PRESENT OUTPUT OF ENERGY.

The sun is the nearest star; and the astronomical data are consistent with the notion that it is reasonably typical of stars in general. The study of stellar energy, then, begins with the sun.

* This paper includes the material of a lecture before The Franklin Institute on Thursday, December 9, 1926, with a few additions.

(Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

COPYRIGHT, 1927, by THE FRANKLIN INSTITUTE.

The first problem is one of measurement—the determination of the rate at which, at the earth's distance, energy from the sun is flowing outward. Investigators include Joseph Henry, Langley, and, especially, Abbot. The "solar constant" is defined as the solar energy which impinges in unit time on unit area of a surface perpendicular to a sunbeam just outside the earth's atmosphere. Its mean value has been determined as 1.94 calorie/min., sq. cm., or 1.35×10^6 ergs/sec., sq. cm.

The measurement of the solar constant is made with an instrument called the "pyrheliometer." A beam of sunlight of known cross-section is allowed to fall on a body of known heat capacity (for example, a blackened silver disc). The energy of the sunbeam is thus completely transformed into heat, and is determined in calories by noting the rate of rise of temperature of the absorbing body. Allowance must be made for heat lost from the absorbing body during the test, owing to imperfect insulation. The results must furthermore be corrected (by a complex method) for imperfect transparency of the earth's atmosphere. It is found that a maximum of only about 70 per cent. of the solar radiation which strikes the upper atmosphere gets through to sea level when the sun is at the zenith and the air is free from dust and clouds.

"A very important and long-continued series of measurements of the solar constant have been made by the Astrophysical Observatory of the Smithsonian Institution under the direction of Doctor Abbot. Observing stations have been located in deserts and on mountain peaks, in order to avoid, so far as possible, difficulties due to water-vapor and dust in the atmosphere; and pyrheliometers have even been attached to small balloons and sent into the upper air 16 miles above the ground. It is planned to continue these measurements indefinitely."

There is evidence of fluctuations in the solar "constant," amounting to 2 or 3 per cent. on each side of the mean. Apparently the sun gives out a little more heat at times when sun-spots are numerous (which happens in eleven-year cycles). It is hoped that, after accurate observations have been extended over many years, the measurements of the solar constant may be utilized in weather predictions. The results of recent determinations are now often printed on the U. S. Government weather maps.

The mean value of the solar constant, 1.35×10^6 ergs/sq. cm., sec., thus represents years of careful observation by numerous

workers. Simple arithmetic suffices to exhibit what a stupendous flow of solar energy this indicates. Since 7.46×10^9 ergs/sec. make up one horsepower, the sun in the zenith supplies about 4,690,000 horsepower per square mile of illuminated territory. Due to imperfect transparency of the atmosphere less than 70 per cent. of this, or 4,000,000 horsepower per square mile, is available at the surface—roughly $4{,}690{,}000 \cos\theta \times (0.70)^{\sec\theta}$ horsepower per square mile, where θ is the angle between the sun and the zenith.

The maximum power output of Niagara Falls is estimated at about 4,000,000 horsepower. At noon on a perfectly clear day in June the sunlight falling on the 133 square miles of Philadelphia is equivalent in power to 100 Niagaras. At noon on a clear day in December the power reaching the same ground area is about 70 per cent. less. (The average rate of consumption of electrical power alone in Philadelphia is something like 300,000 horsepower.)

The solar energy reaching the earth is of course not stored as heat, but (with the exception of relatively small amounts chemically absorbed in the formation of wood, coal, oil, and the like) it is reradiated about as fast as received. If the radiation which strikes the whole earth in a single second could be converted into power, its value, at one cent per kilowatt-hour, would be nearly half a billion dollars.

The surface area of a sphere surrounding the sun, with radius equal to that of the earth's orbit (1.49×10^{13} cm.), is 2.81×10^{27} sq. cm. According to our present knowledge of the physical principles of heat radiation, the sun sends the same amount of energy —1.35×10^6 ergs—outward every second over every square centimetre of this vast area. (For there is no reason to suppose that the earth is specially favored, receiving more than the share of the sun's total radiation to which the small solid angle which the earth subtends from the sun entitles it.) The product of 1.35×10^6 ergs/sq. cm., sec. and 2.81×10^{27} sq. cm. is 3.79×10^{33} ergs/sec. Since space between the sun and the earth is almost perfectly transparent, this enormous quantity is indicated as the total power output of the sun.

Of this the earth intercepts only 1 part in 2200 millions, and all the planets (and asteroids) together only 1 part in about 230 millions. According to our present ideas, the vast remainder

flows out beyond the solar system. Another extremely small fraction is intercepted by the stars this side of the limits of the Milky Way; but most of it may be thought of as passing farther still, to an unknown destination, or to no destination at all.

It is interesting to note the relative amounts of solar energy intercepted by each of the planets. Taking as unity the energy received by the earth, that falling on Mercury is nearly the same, while Venus receives 1.8 times as much, Mars only 0.12 as much, Jupiter 4.5, Saturn 0.90, Uranus 0.044, Neptune 0.017; and all the asteriods less than 0.2. The sum of all these figures is about 9.6.

At one cent per kilowatt-hour, the whole present power output of the sun may be valued at a billion dollars in a billionth of a second. As the surface area of the sun itself is 6.07×10^{22} sq. cm., the power output is 6.25×10^{10} ergs per sec. per sq. cm. of the sun's surface (3.79×10^{33} ergs/sec. divided by 6.07×10^{22} sq. cm.). This amounts to nearly 75,000 horsepower per square yard. (The horsepower developed by the average automobile engine is, roughly, one per square inch of piston area—or only 1300 horsepower per square yard.)

II. THE AGE OF THE SUN.

The next question concerns the time-scale. What is the age of the sun and stars—over how many years has the sun been pouring out this great flood of energy?

This problem, at present, cannot be answered with any degree of accuracy. It is approached first through a study of the probable age of the surface rocks and other geological features of the earth—the "earth's crust." Various methods of estimation have been employed; the most trustworthy seem to be those based on the study of radio-active changes. (The problem of the age of the earth has also been attacked from other angles—well described by Dr. Harold Jeffreys in his book, "The Earth.")

By radio-active transformations, lead of atomic weight 206 is slowly produced from uranium. As the atomic weight of ordinary lead is about 207, the uranium lead may be distinguished by careful analysis. When lead of atomic weight 206 is found associated with an uranium mineral, it is a fair supposition that it has been formed, by the radio-active transformation, in the period during which the mineral has lain undisturbed in the rock.

Laboratory data show that lead is produced from uranium at a very slow rate; 1 per cent. of the uranium would be transformed in about 66,000,000 years. The ratio of uranium lead to uranium, in the geologically very ancient "lower pre-Cambrian" rocks is such that about 1,300,000,000 years would have been required for its production. (The same method gives a small age for rocks geologically more recent.)

These igneous rocks, however, are intrusive into still older sedimentary rocks, laid down under water; consequently the ocean itself must be still older than 1,300,000,000 years. It is reasonable to suppose that the existence of the ocean during this great period of time is strong evidence that the sun's radiation has remained approximately the same. For if the earth had been receiving much more or much less heat from the sun a round billion years ago, the water would have existed only as steam or ice. Furthermore, the record of the fossils shows that vegetable and animal life existed during a great portion of geological time; and this is another indication that the solar constant underwent no serious permanent alteration.

The astrophysical evidence (touched on later in this discussion), on the other hand, indicates that during the whole "life" of a star its radiation alters by a considerable factor. Consequently the conclusion seems forced on us that the past billion years is only a small fraction of the period since the sun began to shine.

III. THE SUN'S TOTAL OUTPUT OF ENERGY.

Having once again, rather inadequately, outlined in a few paragraphs the observational results of many investigators in several sciences, we may return to armchair arithmetic. If the sun has radiated energy at its present rate for the past billion years, it has emitted in that time 1.20×10^{50} ergs of energy (3.79×10^{33} ergs/sec. times 3.16×10^{7} sec./yr. times 10^{9} yr.).

That is to say, one hundred and twenty million million million million million million million million ergs. More than three billion billion billion billion kilowatt-hours (3.33×10^{36}).

Expressed per gram of the sun's mass (which is 1.983×10^{33} grams) the radiation per year is 6.05×10^{7} ergs (1.44 calories); in a billion years at this rate the radiation has amounted to 6.05×10^{16} ergs per gram.

Summarizing our discussion thus far: We began with the

idea of the conservation of energy, and thus the problem arises of finding the nature of the process which produces the flood of electromagnetic radiant energy called, in popular language, sunlight. We proceeded with an account of the determination of the rate at which this energy flows out from the sun. This determination is based upon two observed quantities—the "solar constant" and the sun's distance from the earth.

Then a study of the time-scale, based on the estimation, by means of certain radio-active processes, of the age of the earth's crust, led to the estimate of a billion years as a lower limit for the age of the sun. This estimate, in turn, led to the enormous figure of 1.20×10^{50} ergs, or 6.05×10^{16} ergs per gram of the sun's mass, as the *lower limit* of the energy output of the sun to date. It seems probable that the sun is far older, and that the actual output has been many times greater.

IV. UNSATISFACTORY HYPOTHESES AS TO THE SOURCE OF SOLAR ENERGY.

Now we are prepared to inquire into the physical condition of the sun, with a view toward gaining a knowledge of how this great flood of power originates. Paradoxically, direct observation tells us very little about the sun's physical condition, because we see only the sun's surface, the "photosphere." There is excellent theoretical reason to believe that the whole ball of the sun is composed of hot gases, increasing inward in temperature and density. But the gases become opaque so rapidly with increasing density that we see only the merest "skin" of the sun, the surface layer of gases—only down to where the density is a thousandth part of an atmosphere, or less. This skin which we actually see contains only as much mass as would a layer around the sun of a few feet of atmospheric air.

It is physically unthinkable that the intense energy radiation can originate in the photosphere. It must be produced below, and flow toward the surface. As heat always flows from regions of higher to regions of lower temperature, this indicates that the temperature must increase downward. It is already about 6000° absolute at the surface. (The electric arc and incandescent tungsten filament are at only about 3300° absolute—rather cool in comparison.)

In the light of these known facts certain hypotheses concerning the energy source may definitely be ruled out of the discussion.

Sir William Herschel was one of the ablest astronomers there have been. Working in the late eighteenth century, he opened more than one avenue of investigation which has been followed with profit in the most modern studies. The doctrine of the conservation of energy had not yet been formulated, however, nor was much known about the energy of chemical reactions. Herschel put forward the hypothesis that the sun's heat was produced in an outside *layer of fiery clouds*. The body of the sun itself, he thought, might be cool, and even habitable, resembling the earth in all but size—its surface protected from the great heat by an intermediate layer of dark cloud. The sun-spots he saw in his telescopes (the most powerful that had been constructed) he thought were holes in the fiery cloud, showing the dark masses beneath.

In the *Philosophical Transactions of the Royal Society of London* (1795, part I, page 63), we find him writing, "On the Nature and Construction of the Sun and Fixed Stars":

"Whatever fanciful poets might say, in making the sun the abode of blessed spirits, or angry moralists devise, in pointing it out as a fit place for the punishment of the wicked, it does not appear that they had any other foundation for their assertions than mere opinion and vague surmise; but now I think myself authorized, *upon astronomical principles*, to propose the sun as an inhabited world, and am persuaded that the foregoing observations, with the conclusions I have drawn from them, are fully sufficient to answer every objection that may be made against it."

A second wholly unsatisfactory explanation of the sun's radiation ascribes it to *meteorites* falling with high speed on all parts of the sun's surface, and transforming their kinetic energy to heat. The maximum speed with which the gravitational attraction of the sun can draw a meteorite to its surface is readily calculated as about 619 kilometres per second (being the square root of the quantity, twice the product of the sun's mass and the gravitational constant, 6.673×10^{-8} c.g.s. units, divided by the sun's radius, 6.953×10^{10} cm.). Thus the kinetic energy per gram of falling matter striking the sun is 1.90×10^{15} ergs. To produce 1.20×10^{41} ergs (the sun's radiation in one year) would require 6.3×10^{25} grams. But this (compared with 5.974×10^{27} grams) is $^1/_{94}$ the mass of the earth.

So great a mass of meteoric material could not fail to be

detected as it crossed the earth's orbit, on its way in toward the sun from all directions. If it were falling in from a very great distance, outside the solar system, it would cross an imaginary sphere around the sun with radius equal to that of the earth's orbit at a speed of 42.3 km./sec., and would reach the sun nearly $\sqrt{2}/6\pi$ year, or 27.4 days, later. The earth intercepts 1/2,200,000,000th part of the area of this sphere, and owing to its own gravitational field it would intercept a somewhat larger fraction of the inward falling meteoric material. Each gram hitting the earth would possess 1/215th as much kinetic energy as a gram striking the sun. The earth would receive nearly the same fraction of the outgoing solar radiation as of the incoming meteorites (1/2,200,000,000). Consequently the kinetic energy of the hypothetical meteorites which struck the earth in unit time would amount to 1/215th part (or a little more) as compared with the energy of the sunlight received in the same time. Of course no such enormous energy is received from meteoric material. As the full moon is only 1/500,000th part as bright as the sun, the meteoric illumination of our sky, due to the heating by friction of such a mass of falling particles in the atmosphere, would drown out the moon and all the stars.

On the same supposition as to the rate of fall of meteoric material, the earth's mass would be increased by 1 per cent. in about two billion years. In a hundred million years its radius would be increased by more than half a mile—a proposition geologically absurd, as no deep layers of meteoric dust exist on the land surface or ocean bottoms.

There is no way known, other than by falling meteors, by which much energy could continuously be poured into the sun from without. Consequently the solar energy must be supplied by some sort of process going on within the sun itself—a process which slowly exhausts an enormous initial store.

The next inadequate hypothesis to be dealt with is that of *chemical action*. When carbon burns in oxygen to form carbon dioxide, the energy liberated amounts to only about 3×10^{11} ergs per gram of carbon consumed, or less than 10^{11} ergs per gram of reacting material. But we have found that during geological time alone, the energy source in the sun must have liberated 6×10^{16} ergs per gram of the sun's mass. Consequently the

chemical reaction just mentioned liberates at least 600,000 times too little energy.

No chemical process is known which is enormously more efficient per gram of mass; and what we know of the atom makes it unthinkable that there are such enormously powerful chemical reactions. Consequently chemical processes are totally inadequate to account for the sun's radiation.

The fallacy of hypotheses such as these has been known for years. Helmholtz's suggestion, however, that the energy of solar radiation is supplied by the *contraction* of the whole bulk of the sun itself, under the influence of its own gravitational pull, was believed for a time to be the solution of the problem. It has been computed that a diminution in the sun's diameter by only 280 feet per year would suffice, in this manner, to supply its present radiation. For such a slight rate of diminution in diameter to become detectable with our present telescopes would require more than a thousand years.

The total energy which could be produced in this manner corresponds to the work which would be done by gravitation when the sun's material fell together from an indefinitely great distance; and it can be calculated that this amounts to only something like 2.3×10^{15} ergs per gram of the sun's mass. As the material fell together the kinetic energy of its motion would be transformed, by collisions of its several parts, into heat, and ultimately radiated. The sun's internal temperature is so high that fully half of the 2.3×10^{15} ergs per gram would still be stored as heat in the sun's interior. The remainder would keep it shining at its present rate for "a beggarly fifteen million years or so."

When Helmholtz made his suggestion this was thought about long enough. Nineteenth century physicists were convinced that the earth is cooling off so fast as to have been incandescent a few tens of millions of years ago; and according to this idea the sun need not have been much older. The discovery that radio-active material present in the earth may be giving off heat at a considerable rate, slowing down the speed of cooling of the earth, served to nullify their argument, and to make physically reasonable the geologist's contention that the earth is far older.

The 10^{15} ergs per gram provided by the Helmholtz contraction is 60 times smaller than the 6×10^{16} ergs per gram which

the reasoning of section three sets as a lower limit for the energy process in the sun.

The idea that the solar radiation is supplied directly from heat already stored in the sun, so that the sun gives off energy merely by *cooling*, is closely related to the gravitational contraction theory. Unless the sun contains more heat than contraction from an indefinitely large radius could have supplied, this suggestion contributes nothing new; and if the sun does contain more heat than that, the problem of how it was produced is left unsolved.

There remains another suggested source, which seemed adequate even after the energy of gravitational contraction was proved insufficient, namely, that some *radio-active transformation* of matter, going on in the sun's interior, might supply enough energy to keep the sun shining for the requisite billions of years. The whole amount of energy emitted by a gram of uranium and its derivatives before they settle down into an isotope of lead is about 20×10^{16} ergs. Here at last is a source of something like the desired order of magnitude—although probably still too small.

Definitely to negative the hypothesis that radio-activity of known forms of matter supplies the energy of the sun requires further examination of the problem, but there is strong evidence against its sufficiency. Of course, one may postulate (with Jeans) that deep in the stars heavier and much more powerfully radio-active elements than uranium exist; and that the breakdown of these liberates much more energy per gram.

V. HYPOTHESES WHICH MAY BE VALID.

Desperate occasions require desperate remedies. With radio-activity, all experimentally observed sources of energy have been vainly brought forward. We pass to suggestions which have no experimental backing, but very good theoretical antecedents.

It has been calculated that the *transformation of hydrogen to helium* would yield 670×10^{16} ergs per gram. This calculation is a special application of a more general hypothesis discussed below at more length, namely, that mass can be transformed to energy.

The possibility of such conversion is more or less suggested by the electromagnetic theory of the mass of the electron. The actual formulation of the principle that mass is in some way

equivalent to energy is due to Einstein. Crudely to state the modern conclusion, the doctrines of the conservation of energy and of mass are now generalized to say that not energy alone, nor mass alone, is conserved, but energy *plus* mass.

A loss of m units of mass corresponds to the liberation of mc^2 units of energy, where c is the speed of light (or 2.998×10^{10} cm./sec.). This *constitutional energy* is 8.99×10^{20} ergs per gram, or about 15,000 times as much as our estimate of the sun's radiation per gram of the sun's mass during the past billion years.

This, if Einstein is correct, represents the maximum production of energy, per gram of mass involved, of any process whatsoever. Consequently, just as our figure of 6×10^{16} ergs per gram serves as a lower limit for the efficiency per unit mass of the source of solar energy, so this figure of 8.99×10^{20} ergs sets an upper limit—hardly to be transgressed by future generations of investigators, however affected with megalomania as to the scale of astronomical and geological time.

On the ground of the principle of the equivalence of energy and mass, it is as reasonable to speak of a "ton of energy" as of a "ton of matter"—but the former is three hundred times as much energy as the electrical power stations supply in the United States in a year, and would be sufficient to lift the moon sixteen inches farther away against the gravitational pull of the earth. On this basis the sun is losing *4,660,000 tons of energy per second*; and the sun's mass must be diminishing at that rate. Of this energy the earth receives every second 4 pounds, 3 ounces, avoirdupois.

The study of solar energy leads us, then, to examine all known energy-producing processes, and to reject most of them as inadequate. The energy possessed by bodies in virtue of their speed is quite insufficient, as proved in the case of the falling meteorites. The energy possessed by the parts of the sun in virtue of their positions in the solar gravitational field is likewise too small. The energy possessed by the electrons concerned in chemical combination is absurdly inadequate; these are the "valence" electrons, which lie at the outer parts of atoms. Even the innermost electrons of atoms, deep in the "completed shells," or parts of the structure which are disturbed only by the intense action of hard X-rays, possess energies many times too small to be of help in explaining the origin of the sun's heat. We penetrate with the physicist

to the tiny atomic nuclei, where the electrons are bound to positive charges by forces which presumably vastly exceed those active in the shells. Even here the known energies, which manifest themselves in radio-active transformations where the elements themselves are changed, are not large enough.

The old maxim that "great oaks from little acorns grow" is pertinent to the physicist's experience that the greater the intensity of energy produced, the smaller is the material system which liberates it. Not in meteoric dust, nor in the chemical structure of the atom, nor even in its nuclear structure, does the astrophysicist find systems certainly capable of producing the vast energies he observes. But in the very smallest sub-structures physics has yet vaguely imagined, in the unknown conditions which shape the skins of electrons and keep matter from self-annihilation, energies are gathered together which may be admitted as sufficient.

How often, and due to what causes, matter may vanish and its constitutional energy be liberated is at present to be studied by observations not of atoms but of stars. In physics the problem has been one of only speculative interest; but in astrophysics there are definite observational relations which, we suppose, will only be explained through some understanding of the physical conditions governing the liberation of solar and stellar energy.

VI. THE PROBLEM OF DETERMINING THE INTERNAL CONSTITUTION OF A STAR.

We turn, then, to astrophysics, and to a discussion of conditions deep within the sun and stars. It is there that the "unknown source" of stellar energy must be presumed to operate—whether it functions by the liberation of the constitutional energy of matter or in some other fashion. As already stated, we cannot see to any depth within the sun. A quotation from "Love's Labour Lost" is quite to the point here (and has been employed by Professor Eddington in the preface of his just published book, "The Internal Constitution of the Stars"). The reference is to "heaven's glorious sun, that will not be deep-search'd with saucy looks." Having failed with our saucy telescopes to penetrate the surface of the sun, we in some measure succeed with what Eddington has called "an analytical boring machine." That is to say, we proceed by mathematics, step by step below the visible surface,

relying on our knowledge of the properties of matter as determined by laboratory experiments, and on our acquaintance with the "macroscopic" properties of the sun—its mass, volume, total radiation—and its surface temperature.

This analytical exploration is one of the strangest flights ever taken by the scientific imagination. The distance from the photosphere to the centre of the sun is about 430,000 miles. Hundreds or thousands of astronomers have ranged in fancy over the vastly greater spaces which lie between the stars; but only a very few pioneers have directly attacked the intricate physical problems which beset the explorer who would plunge beneath their photospheres. Lane, about 1880, Emden, about 1907, Eddington, Russell, and Jeans, have been leaders in the advance. The reports of these investigators are not in entire agreement; the maps they make of stellar interiors show important discrepancies, and, in a conservative view, may be as crude as were the early delineations of the Americas. But the start has been made, and the new provinces of physics have been opened for a detailed investigation which well may require another century.

Two physical formulas are the principal vehicles which carry us beneath the sun's surface.

The first is derived from the supposition that the matter everywhere in the sun is in gravitational equilibrium, that the forces acting upward just balance the forces downward. The downward force acting across any surface within the sun, normal to a radius, may be thought of as the weight of the overlying material. The balancing upward force is supplied by the pressure of the material in that region. According to Newton's law of gravitation the portion of the sun within a given spherical surface about the sun's centre pulls the remainder—the shell lying outside—downward, that is, toward the centre, with a force, or weight, that is readily calculable when the distribution of the sun's mass is known. Of course this distribution, to begin with, is not known, for that implies a knowledge of the density of the material at every point within the sun. All that is certainly known is the total mass.

Naturally we expect the density to increase downward; and if a plausible relationship is assumed between density and distance from the centre, the law of gravitation establishes, correspondingly, the weight of overlying material, and hence the pressure, at every point. But as far as this part of the argument goes, almost

any arbitrary law of variation of density with distance is permissible, provided only that the separate regions sum up to the same total mass. Additional formulas are needed before we can compute the internal constitution of a star.

Eddington employs a second principle, namely, that the matter everywhere in a star is also in thermal equilibrium. For in addition to the gravitational force and the pressure we must consider the flow of energy, or heat, within a star. The principle of the conservation of energy requires that the energy which flows, in unit time, out of a given region must be the sum of that flowing into the region and that liberated in the region. It seems reasonable to suppose that a star is almost in a steady state, so that the energy liberated or absorbed by the very slow heating or cooling of the given region is very small compared with that which flows into and out of the region in the same time. Likewise, it turns out that the "unknown source" of stellar energy—presumed to be distributed pretty well throughout the star—liberates in the given region energy, whether by the annihilation of matter or otherwise, at a rate extremely slow compared with the rate at which energy is flowing through.

The flux of energy at any point may be supposed calculable when the physical conditions, and especially the temperature, at the point are known. Since the physical state of the material may be supposed to be determined chiefly by the density and temperature of the region, it follows that the energy-flux is calculable when the density and temperature are known.

But we already have seen that the law of gravitation permits calculation of the pressure at every point when an arbitrary density distribution is assumed. As the pressure likewise may be taken as a definite function of density and temperature, when the physical condition of the material is known, it follows that an initially assumed arbitrary distribution of density leads to a calculable distribution of temperature, as well as of pressure, and hence to a determination of the energy-flux at every point within the star. A different initial assumption as to the density distribution would of course give different results; and these so far would be essentially arbitrary. It is assumed in this argument that the physical condition of the stellar material is known, at the given density and calculated temperature. Eddington thinks

that most stellar material behaves as an "ideal" or "perfect" gas; and supports this hypothesis with detailed arguments.

The heat conductivity of the material, or its transparency to the flow of energy, also may be supposed to be a function of its temperature and density. The net rate of outward flow of heat across any spherical surface within the star can be shown to be proportional to the product of the conductivity of the material at that surface by the radial gradient of the energy-flux—that is, by its rate of diminution with respect to increasing radius. Consequently the net outward rate of flow of heat is calculable at every point in the star, from data dependent on the initially assumed density distribution. (At any point in the star energy is flowing in every direction; the net outward flow is equal to the total outward flow less the inward flow.) Consideration of the calculated net outward flow of heat serves to rule out many density distributions as physically unreal. For near the surface the flow must be nearly equal to the energy radiation of the star, which of course often can be determined by observation, independently of our arbitrary assumption as to how the density varies with depth within the star. Since the state of the star has been assumed to be practically steady, the net outward flow of heat across any spherical surface concentric with the star must be the same as the quantity of energy liberated within that surface in the same time. Consequently, at increasing depths, the net outward flow of heat should diminish, since it is supplied by energy liberated only by such quantities of the "unknown source" as lie still deeper within the star.

Indeed, if the law of liberation of energy from the "unknown source" were known, as a function of the physical and chemical conditions of the material at every point, then this line of argument would suffice (except in cases of special relationships among the factors involved) mathematically to determine the constitution of the star. For, of all arbitrary density distributions, that one would be selected as actual which led to the correct rate of increase outward from the centre of the net flow of heat, that is, to a rate of increase which would just agree with the rate of liberation of energy from the "unknown source" in the corresponding region.

Since we are ignorant of the law of liberation of energy, a

rigorous determination of the internal constitution of a star by this means is at present impossible.

VII. THE STELLAR MODEL PROPOSED BY EDDINGTON.

We have seen, however, that the net outward flow of heat just below the surface of a star—that is, its total radiation of energy—can be computed when the mass of the star and the mode of distribution of the mass are given.

In 1924 Eddington found that a certain simple assumption indirectly defining this mode of distribution leads to *an equation which relates the total radiation from the surface of a star to its mass.* Bringing together all the observational determinations of the masses and the real brightnesses of stars, he showed that such a connection between mass and luminosity actually exists, at least when averages are taken over a number of stars. (The real brightness of a star, technically called its "absolute magnitude," can be computed from its apparent brightness, as seen from the earth, when the distance, or parallax, of the star is known. The mass can be found directly only if the star is a component of a binary system and the orbital motions of it and its companion can be observed. A study of these motions permits computation of the gravitational pull of each star on the other, and so of the masses.)

Such observations show that the average star of mass 1/7th the sun's has a brightness only about 1/12,000th part of the sun's; if the mass is one-half the sun's, the brightness is about 1/19th part of the sun's; the average star of equal mass has equal brightness; the average star of mass ten times the sun's has a brightness roughly 500 times as great. Few stars are known which have masses and brightnesses much greater or much less than these limits.

Eddington's theoretical relation (based chiefly on general principles of physics and the laws of atomic behavior, our knowledge of which has no dependence on astronomical data) is in surprisingly good agreement with this relation observationally discovered. Whether or not details of his theory remain permanently in their present form, this achievement commands the deep interest and respect of all students of physical science. He has been especially adept in separating intrastellar physical

processes which play important parts in the equilibria from those which may be considered unimportant.

If the sun actually is constructed according to Eddington's model, the material is throughout in the state of a nearly perfect gas. The density increases toward the centre at such a rate that the density at the very centre is about 54 times the mean density. Since the latter is readily calculated, from the known mass and volume of the sun, as 1.41 grams/cm.^{3}, this makes the central density about 76.5 times that of water, or more than three times greater than that of platinum. In ordinary laboratory experience, of course, no gas has ever been observed of anything like so great a density—but the gas at the centre of the model sun is under a pressure of more than a billion atmospheres, and at a temperature of nearly 40 million degrees absolute (centigrade degrees).

A pressure of a billion atmospheres is equivalent to a weight (at the earth's surface) of 7.3 million tons per square inch—the weight of perhaps 150 of the largest ships, concentrated on every square inch, or of a cube of rock more than 350 feet on a side.

To raise one pound of matter, of specific heat remaining equal to that of water, to a temperature of 40,000,000° would absorb 21,000 kilowatt-hours of energy; and when it cooled again it would give off enough energy to run a high-powered automobile continuously for a couple of weeks.

There is no immediate likelihood that direct laboratory experiments will be made to test the properties of matter under conditions duplicating those deep in stars. That the pressures and temperatures there are very high is a necessary consequence of any theory, although the exact values depend upon the "model" adopted. Our belief that we know something about how matter behaves under such conditions rests upon our basic theories of atoms, of gases, and of radiation; and upon the interpretation of laboratory experiments which have an indirect bearing upon the cases in point. Thus when metals are bombarded with high-speed electrons and exposed to X-rays, the individual atoms are, we think, being subjected to conditions approximating those prevalent at intrastellar temperatures.

The idea that matter could be compressed to a density greater than 75 times that of water and yet remain in the state of an approximately perfect gas is an interesting by-product of Edding-

ton's study. In the laboratory, gases cease to obey the Boyle-Gay-Lussac law when subjected to moderate pressures; but at the high temperatures deep in stars the individual molecules are highly ionized. Their outer shells of electrons are torn off by the intense radiation and frequent collisions, and the kernels remaining are so very much smaller that the gas remains "perfect" at far higher densities.

This matter of calculating the ionization of a gas when the temperature and pressure are known is one important step in estimating the physical state of intrastellar matter. Another problem of importance, as yet only imperfectly solved, is the computation of the opacity, or resistance which the material offers to the flow of energy. A third problem is that of stating the total pressure when the density and the temperature are given.

In this connection Professor Eddington has emphasized the importance of pressure of radiation. In section 5 we calculated that 4 pounds, 3 ounces of solar radiant energy struck the earth per second. If we think of this mass as flying with the speed of light it evidently carries a great deal of momentum, which is imparted to the earth when the radiation is absorbed. The corresponding pressure of radiation against the whole earth is equivalent to a force of about 64,000 tons weight (5.73×10^{13} dynes). (The solar radiation striking the illuminated hemisphere of the earth per second amounts to 1.72×10^{24} ergs; and exerts a total force in dynes which is computed by dividing this figure by 2.998×10^{10} cm./sec., the speed of light.) This is quite negligible in comparison with the gravitational force of 4.0×10^{18} tons weight between the sun and earth (3.57×10^{27} dynes). Deep in stars, however, the radiation at the high temperatures must be extremely intense, and the radiation pressure takes a large share in balancing the gravitational pull. In computing the energy and pressure of radiation deep in stars, it is assumed that the Stefan-Boltzmann law applies—according to which the pressure of radiant energy in a *vacuum* within an opaque enclosure with material walls at absolute temperature T is aT^4, where $a = 2.54 \times 10^{-15}$ when T is given in centigrade degrees and the pressure is in dynes/cm.^{2}.

Eddington has presented calculations of the ratio of radiation pressure to the total pressure (which is the sum of the pressure of the stellar gas and the radiation pressure) for stars built

according to his model. This ratio is very small for hypothetical stars having masses less than 10^{33} grams, and is practically unity for hypothetical stars of mass greater than 10^{35} grams. Only when the mass is between these limits is there anything like equality between gas pressure and radiation pressure. It is, he thinks, a significant fact that these are the very limits which include the masses of actual stars. (Incidently the distinctive feature of Eddington's stellar model is that throughout a given star radiation pressure bears a constant ratio to total pressure. For example, in the sun radiation pressure is computed as being everywhere about 5 per cent. of the total pressure, the other 95 per cent. being supplied by gas pressure. In Capella the radiation pressure is 28 per cent. of the total.)

The principal direct check on Eddington's theory of stellar constitution is the fairly close agreement between the computed and observed mass-luminosity relation. It would be dangerous to conclude that the theory is at all points correct. Many groups of physical assumptions, explicit and implicit, have been made in deducing the theoretical mass-luminosity relation, and we must not be overly certain that these all are correct because a single observed relationship is rather roughly explained. The problem of stellar constitution, even in its lowest terms, is far more complicated than the kinetic theory of gases—and, in the latter, several matters have not been entirely clarified by the great amount of attention they have received since Maxwell's day.

In laboratory studies matter can be separated into its various elements, and the transformations of energy can be restricted to certain modes; but in stars all kinds of matter and, probably, all forms of energy are mixed and reacting together. Furthermore, in a star the conditions at any point are not arbitrarily assignable, but have been set up after thousands of centuries of mutual interactions between the various parts of a single system—the star as a whole.

According to the argument of section 6, if a formula were available relating the liberation of energy from the "unknown source" to the physical conditions of the stellar material, our mathematics would suffice exactly to determine the make-up of a star. This view of things has been taken in all work on the subject. If certain relationships exist, however, among corresponding terms of the equations for the gravitational and ther-

mal equilibrium within a star, one of these equations becomes a mere repetition of the other; and the problem of defining the internal constitution would then become indeterminate, unless some further factor, in addition to the principles of ordinary physics and the laws of atomic behavior, were brought to bear upon it. Such a state of things would necessitate giving the concept of a star as a system a real rôle in the solution. The results of this application of the conditions for indeterminateness to the two equations mentioned are not in accord, however, with present views as to the way energy is transported within a star (*i.e.*, chiefly by radiation).

As a speculative possibility, nevertheless, the way seems still open for a theory which shall treat a star as "microscopically" indeterminate, in the sense in which a gas is molecularly indeterminate. The molecules of an ideal gas act upon one another according to definite mechanical laws; but the gas laws theoretically are derivable from the mechanical laws only through the introduction of the concept of probability, and the employment of the methods of statistical mechanics, which deal with the whole body of gas at once. In seven thousand litres of gas (a cube six feet, three inches on a side) under standard conditions the average volume assignable to each molecule is one part in nearly two hundred trillion trillion; but the volume of the sun (1.40×10^{33} cm.^{3}) is larger than seven thousand litres by the same factor of 2×10^{26}. Each six-foot cube of solar material acts upon the adjacent cubes according to definite physical laws; but it may be that these laws alone are insufficient to determine the behavior of the star as a whole—which is what astronomers are chiefly interested in knowing. (We have no reason to believe, however, that each six-foot cube is really functioning as a sort of "solar super-molecule," and the illustration need not be carried farther here. Indeed, to put forward such an unsupported speculation may seem rather superfluous in view of the success of Eddington's detailed attack from a different angle.)

VIII. THE LIFE-HISTORY OF A STAR.

The connection observationally established, between the luminosity and the mass of a star, has not been of much immediate help in the study of the source of stellar energy, for, as outlined in sections 6 and 7, a theory such as Eddington's of the con-

stitution of stars accounts for the observed relation without the necessity of scrutinizing the mode of liberation of the energy. Bodies of stellar mass must be heated to great temperatures internally, in order to be distended to stellar volumes. Being so heated, they necessarily shine with stellar luminosity—according to calculations of the flow of heat outward, down the estimated temperature gradient and through material of the estimated opacity. An interesting point won from this discussion, bearing on the nature of the energy-producing process, is that the energy must be liberated in the deep interior, rather than put in from without (as by falling meteorites) and liberated near the surface; for, as Eddington points out, the latter type of process would not keep the interior at the necessarily high temperatures.

We must consider a different class of astronomical data, really to come to grips with the elusive "unknown source" of stellar energy, data which possess a bearing on the nature of the changes which stars undergo during very long periods of time.

For example, there is a class of stars known as "Cepheid variables"—so called because δ Cephei was the first one noticed. The brightness of such a star is observed to vary periodically, in a distinctive manner. It is thought that the Cepheid characteristic may be due to pulsations, that is, to expansions and contractions in radius. If such is the case, any alteration in the mass, density, or mean radius of the star would result in a change in the period. Since δ Cephei has been under accurate photometric observation for a great many years, and during that interval has repeated its cycle of variation (in a period of 5.37 days) many thousands of times, a very slight change in the period would clearly be indicated by the observations, but these show no change greater than at most, $0.^s1$ annually. If the radiation of this star was supplied by the gravitational energy released by contraction, as postulated by Helmholtz, the radius, according to a calculation of Eddington's, would be decreasing annually by one part in 40,000, and the period decreasing annually by 17 seconds. The evidence of other Cepheids is also against changes of this sort. Consequently it may be stated that no appreciable fraction of the radiation of these stars is supplied by contraction.

The relationship between the luminosities and the surface temperatures and diameters of stars is of fundamental importance to an investigation of the mode of production of stellar energy.

The fact that astronomical observations show the existence of such a relationship, so striking as to serve to classify all stars into three or four distinct groups, was discovered about fifteen years ago by Hertzsprung and by Russell.

First there is the group called "giant stars," all of which possess high luminosities. The surfaces of some stars are relatively cool, below 3000° absolute; and the fact that the luminosities of certain of these are great means that their diameters are very large, since the brightness per unit area of surface is low at the low temperature. Thus Antares, for example, has a surface temperature of 3100° absolute and a diameter 450 times that of the sun (which makes it larger than the orbit of Mars), with a corresponding radiation of energy about 3500 times the sun's. (The mass of Antares, however, is probably no more than 40 times the sun's, and thus its mean density very low, less than 3×10^{-4} gram/cm.^{3}, or at least four times less than that of atmospheric air.) Other giants have hotter surfaces, ranging well over 10,000°, and the brightness per unit area of these stars is presumably greater; but their diameters are smaller, and their luminosities are, on the average, no greater. Since their masses are not much different, the densities of the hotter giants are higher than those of the cooler.

A second class of stars is recognized as belonging to the "main sequence"; the surface temperatures of these range downward from 15,000° or so, but the cooler stars of this kind are, unlike the cooler giants, smaller and denser than the hotter ones. Consequently the cooler stars of the main sequence are much fainter than the hotter ones, as the diminution of size and surface brightness conspire to lower the luminosity. They are also far fainter than the giants which have the same surface temperature, being so much smaller; and, since radiation from a surface at 3500° absolute is decidedly reddish in color, the stars at this end of the main sequence are known as "red dwarfs." They are a hundred times fainter than the sun, with diameters several times smaller. There is very little distinction between the hottest white giants and the main sequence stars of the same temperature; the two groups merge together in these stars.

There are also a very few stars known of a class called "white dwarfs." These are as faint as the red dwarfs, but still more condensed, having diameters thirty or more times smaller

than the sun. There is good evidence that matter in these stars is concentrated to huge densities, scores of thousands of times that of water. A cubic inch of white dwarf material weighs about a ton. This may seem to be a very tall story—as tall as the seven upper stories of the hotel which was so high that they had to be put on with hinges and dropped down to let the moon pass by. But by a study of its light we can measure the surface temperature of a white dwarf, and so compute the brightness of unit area of its surface; we can measure its total brightness, and, dividing this by the brightness per unit area, derive its total area, diameter, and volume; and if the dwarf happens to be one component of a visual binary we can determine its mass, and consequently its density. In the case of the companion of Sirius the measured redward "relativity shift" of the lines in its spectrum gives satisfactory quantitative confirmation of the great density.

There must be deep significance in the fact that every one of the hundreds or thousands of stars for which the requisite data are available falls into one of these three classes—giants (including the very brightest "super-giants"); main sequence stars (including yellow and red dwarfs); white dwarfs. For if the relationship between brightness or mass and diameter or surface temperature were merely a random one, a star of given brightness and mass might have almost any diameter, and there would be stars intermediate between the giants and the dwarfs; so that the fairly sharp classification just described would not be indicated.

For a number of years the following partial interpretation of these relationships was accepted. It was elaborated principally by Prof. H. N. Russell, who revived in a somewhat altered form suggestions made by Lockyer. The bulky, relatively cool, and very rarefied giants, according to this theory, were young stars, just beginning to shine. Assuming that its radiant energy was furnished by a Helmholtz contraction, such a star, according to simple physical principles that had been worked out by Lane, would for some time grow hotter as it grew smaller, and thus might retain about the same brightness, passing through the "giant" stage. But, as it contracted, a critical point was supposed to be reached, when the gas became too dense longer to obey the Boyle-Gay-Lussac law, and after this the star would continue to contract but would grow cooler and so fainter, pass-

ing through the white and yellow main sequence types and in time becoming a relatively dense red dwarf. (The existence of white dwarfs was puzzling.)

Just as (following Herschel's picturesque analogy) trees of all ages and sizes may be seen in a forest, permitting an observer in half an hour's walk to gain a correct idea of a century's life-history of a tree; so the astronomer with a few years of precise study of hundreds or thousands of stars may be supposed to have found examples of all stages in the life of a single star.

Russell's theory has played an important part in the development of astrophysics; but it is now looked upon as unsatisfactory; and we are left, for the time, without an accepted hypothesis as to the life-history of a star. Eddington's discovery that the mass-luminosity relationship applies to giants and dwarfs alike has invalidated the hypothesis that the white giants have reached a critical density and that these stars stand at the sort of turning point of temperature described by Lane's equations. As has already been stated (section 7) gases may be supposed at intrastellar temperatures to continue to obey the Boyle-Gay-Lussac law at densities far higher than those of the white giants.

The mass of observational data upon which Russell's theory was based, many of which were first brought together by him, are still regarded as sound; and it is believed that their correct interpretation will set us well forward upon our search for an understanding of the mode of production of stellar energy. The fact that the redder stars fall into two distinct classes, giants and dwarfs, is especially important in this connection. There are very few or no stars in the gap between the fainter red giants, with masses not less than three and one-half times the sun's, and the brighter red dwarfs, with masses one-half the sun's. That the bulky, rarefied red giants are among the younger stars seems the plausible assumption. The indication is, then, that a star in passing from the red giant to the red dwarf stage (by whatever route) radiates away six-sevenths of the original mass. (It is not supposed that a star can lose much mass otherwise than by radiation—unless indeed it divides into two stars, forming a "binary"; but numerous red dwarfs exist which do not belong to binary systems.)

Study of the orbits and relative masses of the components of binary systems points, although not with certainty, to the con-

clusion that many such systems are very old indeed, perhaps of the order 10^{13} years in age—so old that such stars must have radiated energy equivalent to a large fraction of their original masses. This evidence, for what it is worth, is confirmatory of the conclusion that the "unknown source" is the annihilation of matter with the release of its constitutional energy.

The study of the stages through which a star may be supposed to pass during its existence is sometimes called the study of stellar "evolution." This use of the word *evolution* seems questionable, as the life of individual stars is all that is under consideration, and there has been no suggestion that a star passes on its distinctive characteristics to younger stars. Indeed we do not know with certainty whether stars are at present still being "born" or not.

Stars that are found together in revolving pairs ("binaries") presumably were formed from a single star by fission. Stars that occur together in large clusters likewise may be presumed to have been in existence about the same length of time. Comparisons among such stars afford interesting tests of theories relating to stellar life-history.

Again, comparison of the numbers of stars of different kinds —for example, the relative numbers of red dwarfs and red giants—may be taken as indicative of the relative intervals of the time consumed in passing through the various stages. There are a great many fewer giants than dwarfs, per unit volume of space, which indicates that stars remain much longer in the latter stage. (Without telescopic aid, however, we see very few dwarfs, since they are relatively faint; we can see the giants at far greater distances.) Russell, Jeans, Eddington, Shapley, and others have entered into discussions relating to these points.

A definite hypothesis as to the mode of release of stellar energy runs up against the difficulty of relating the average energy produced per second per gram of the whole mass of a star to the other characteristics of a star. Thus, in the sun (a yellow dwarf), the energy production is 1.91 ergs per second per gram of the sun's mass. In Capella, a giant star of lower mean density and presumably somewhat lower temperature at corresponding points through its interior, the liberation is nearly 60 ergs/sec., gram. Inside the earth such energy production as there is must amount to a great deal less than the heat received

from the sun, which is only 2.88×10^{-4} ergs per second per gram of the earth's mass. If the liberation of energy from the "unknown source" increases with the temperature and density of each given region in a star, as one hypothesis has it, then (as Eddington has stated) the lower rate in the sun as compared with Capella can be ascribed to relative exhaustion of the supply in the sun, a presumably older star.

At the centre of Eddington's model of the sun, one gram of matter occupies a volume of 1/76.5, or 0.013, c.c. If we consider an imaginary cube, of this volume, at a temperature of 40,000,000° absolute, the gross flux of radiant energy across its surface (according to the Stefan-Boltzmann relation) is $(0.013)(7.63 \times 10^{-15})(2.998 \times 10^{10})(4 \times 10^{7})^4$, or 7.66×10^{24} ergs per sec. This is enormously greater than the average amount of energy liberated, from the unknown source, per second per gram of the sun's mass. Thus the hypothesis mentioned in section 6, that a star is in a thermally steady state, receives justification.

The necessity of making our stellar model stable is a cause of intricate trouble to the investigator with a theory as to how the "unknown source" liberates energy. If it is postulated that the liberation depends in such and such a way on temperature and density, for example, one must make sure that the assumed relation is not such that a slight disturbance would cause the energy liberation to increase so rapidly as to blow up the star. (Rare catastrophes known as "novæ" or temporary stars are, indeed, observed in the heavens; but there is some reason to suppose that such an event is merely a superficial disturbance in a star, not destroying it utterly. On the other hand, in the pages of recent numbers of the *Monthly Notices of the Royal Astronomical Society*, the stellar model proposed by one investigator is sometimes blown up by another after a life of a few months.)

The reader interested in following the most recent, rather controversial, discussion as to the nature of the process producing stellar energy is referred to papers by Doctor Jeans, and others, in the periodical just cited, to Professor Eddington's recent books, and to the outline of Professor Russell's views given in the final chapter of the revised Young's "Astronomy" (Russell, Dugan, and Stewart; Ginn and Company, 1927). (Material from the last of these publications has been freely employed in the present

paper—the writer of which, in addition, owes special personal acknowledgments to Professor Russell.)

Jeans is in disagreement with Eddington in many matters, both as regards the constitution and the life-history of stars. He is of the opinion that if stellar material behaved like a perfect gas the stars would be unstable. In arriving at a theory of the "unknown source," Russell finds significance in the fact that, according to Eddington's calculations, the central temperature of all stars of the main sequence is the same, about 40,000,000°; while the temperature of all giants is less. He suggests that in the giants energy is released by one process, and in the main sequence stars by a second process—using up first an unknown material that for convenience may be called "giant stuff," and then tapping a much larger reservoir of "dwarf stuff." The consequences of these hypotheses are compared with the various observational data.

Adequately to criticize all this discussion would expand the present paper beyond all bounds, and, in addition, would at certain points lead beyond the limitations of the knowledge of the writer.

The situation will doubtless have clarified somewhat within a few years. The important thing is that while we know very little about the mode of operation of the "unknown source," this little is capable of being applied, and is being applied, to the elucidation of definite astrophysical problems. When the astrophysical evidence has all been collected and interpreted, it seems certain that the student of terrestrial physics will be presented with new data and new principles which will take an important and enduring place in the science.

The phrase, "When the astrophysical evidence has been collected," is an easy one to write; but the elaborate task of accumulation of that evidence must not be passed over so briefly. If the work of every individual who has made an important contribution to our acquaintance with the physical nature of stars were described here, the great cathedral of knowledge that has been so imperfectly sketched would be far more truly exhibited—not as the construction of a half dozen investigators within a few decades, but as the slowly growing product of thousands of minds and centuries of thought. Its foundations are the sum of the accomplishments of the men who invented the

telescopes, of the men who cast and ground the lenses, of the men who devised and used the spectroscopes, photometers, bolometers, cameras, interferometers, pyrheliometers, clocks, of the surveyors whose accurate terrestrial baselines were projected into the skies —first to the moon, then to Venus and Eros and the sun, to α Centauri, to the boundaries of our Galaxy, and now to the spiral nebulæ. Mathematicians, physicists, chemists, geologists, astronomers, inventors, instrument-makers, engineers, teachers, and the donors of observatories, libraries, and laboratories; the interlocking patterns of their work remain, and will serve to guide their successors in new achievements of increasing intricacy and brilliance. If efficient and rewarded application of human effort is made the criterion of historical importance, then national or social jealousies and continental wars are trivial and temporary things beside such an example of the fruits of international coöperation as is afforded by our increasing knowledge of the stars.

IX. FUN WITH ARITHMETIC.

Leaving now the scientific efforts toward discovery of the source of stellar energy, we may pass to a speculative discussion of the consequences in engineering of the utilization of the stellar source, should this ever be brought about. Such exercise of the imagination needs no special justification, but may find it in the fact that all, or nearly all, of the energy now employed in industry and transportation traces ultimately to sunlight. Thus wood, coal, and oil represent sunlight stored millenniums ago as chemical energy in organic compounds. The energy of winds and waterfalls presumably derives from sunlight. (That of tides, however, comes from a slight slowing of the earth's rotation.)

We have seen that the source of solar energy must be capable of releasing (given time enough) at least 6×10^{16} ergs per gram of the sun's mass, and probably many times this much. If the conclusion indicated by some of the astronomical data presented in section 8 is correct, that stars radiate away large fractions of their masses, then the energy released is of the order 10^{20} ergs per gram. For definiteness let us "go the whole hog" and suppose that some day, first in our physical laboratories, then in practical machines for industrial use, we find how to convert the whole constitutional energy of matter into usable energy, at any desired rapidity of conversion and with perfect efficiency.

The energy released from one gram, with the complete disappearance of the matter (nowhere in the universe would the lost atoms be found) then may be assumed as 8.99×10^{20} ergs, or 2.50×10^{7} kilowatt-hours, or 2850 kilowatt-years, or 3820 horsepower-years. This is the equivalent in heat value of more than 3000 tons, or 3,000,000,000 grams, of pure carbon burnt in oxygen. While we are indulging in these fancies, there is nothing to keep us from supposing that any chemical substance could be thus transformed. Any substance whatsoever, then, could serve as a fuel over three billion times as efficient, per unit weight, as coal or oil. Here are some amusing examples of the speculatively possible results.

(*a*) The constitutional energy of a bucket of sea-water would be sufficient to drive for more than a month the engines of the merchant-fleet of the world (25 pounds × 454 grams per pound × 3820 h.p.-years gives 4.3×10^{7} h.p.-years; and this divided by 20,000 h.p. and 15,000 ships yields 1/7 year).

(*b*) The constitutional energy of a breath of air (assuming that in normal breathing a breath occupies 300 c.c., and weighs 0.4 gram) is 1500 horsepower-years, and would operate a powerful aeroplane for two years continuously.

(*c*) The constitutional energy of a handful of snow (30 grams × 3000 tons of anthracite as the equivalent per gram) would heat a large apartment house for many winters.

(*d*) The constitutional energy of the pasteboard of a small railway ticket would run a heavy passenger train at 60 mi. per hr. for four months, or seven times around the earth's equator (a ticket from Princeton to Philadelphia weighs 0.3 gram; 0.3 gram × 3820 h.p.-yr. divided by 3600 horsepower gives 3.8 months).

(*e*) The constitutional energy of a gold dollar (1.67 grams) is, at one cent per kilowatt-hour, worth four hundred and sixteen thousand dollars. That of a dollar bill (about 1.6 grams) would be worth nearly as much. Consequently, burning U. S. banknotes of even the ten-thousand dollar denomination in a suitable engine would be a very lucrative source of power.

After these illustrations of how much work a few grams of energy would do, we are in a better position to appreciate the full force of the statement that the sun is radiating 4,660,000 tons of energy every second.

Most of these figures may be diminished ten-thousand fold without seriously impairing their emphasis; and there seems little doubt that the source of stellar energy is more powerful than that. Of course, astrophysicists cannot guarantee that they will soon come to a comprehension of the process which liberates energy in the stars—much less that inventors will ever be able to make practical applications of the "unknown source." It is certain, however, that from such studies as Eddington, Jeans, Russell, and others are now undertaking, important practical results of some sort or other will some day flow. Another quotation from the same Shakespearian play is again applicable—although in a different sense from that intended by the playwright.

> "These earthly godfathers of heaven's lights,
> That give a name to every fixed star,
> Have no more profit of their shining nights
> Than those that walk and wot not what they are."

X. (IF A PHYSICIST MAY BE PERMITTED TO SERMONIZE.)

There is another side of the picture, one not at all cheerful. We have just been counting our chickens before they are hatched —but are we sure that they are not going to be formidable monsters instead of chickens? Energy can be put to destructive as well as to constructive uses. The energy some day derivable from a breath of air may drive an aeroplane at 250 miles an hour or at any other speed; but all of us who remember 1914–1918 know that this possibility is not justification for unmixed optimism. A projectile started at a speed of six or seven miles a second could be caused to strike and explode in a city thousands of miles distant, even at the antipodes, perhaps.

If such are to be among the uses of the new sources of energy, it would be well for society if every member of the little band of "earthly godfathers of heaven's lights" were immediately and finally deprived of his spy-glass and slide-rule. That is one solution, but it is too superficial and cowardly to be correct. The better way is for all of us to recognize the overwhelming importance of the *indirect* results of certain courses of action. The whole development of the mechanical basis of present-day civilization is a proof of the importance of indirect results. Galileo and Newton attempted the solution of certain problems in mechanics. The immediate material consequences were very

slight; but their methods and conclusions, put out in the hands of succeeding generations of scientific workers, have yielded interest compounded over and over again. During these same centuries, far greater social efforts have been devoted to other projects which have yielded no return or a negative one.

Of the men of science it may indeed be said that they toil not, neither do they drive other men to toil; yet all the slave-labor power of antiquity was trifling compared with the power of our modern motors. And, as this paper has attempted to indicate, the power of these is trifling in comparison with that of the anticipated machines of the coming years. We are told sometimes that demand for coal and oil will be the cause of future fighting. But the value of coal was not recognized until a few centuries ago, and that of mineral oil only half a dozen decades ago. Seventy years from now, if suitable research is encouraged, there doubtless will be acceptable substitutes for coal and oil.

The plain fact is that the mechanical framework of our civilization is an embodiment of the scientific spirit. Unless it is employed in a spirit at least as high, social chaos is going to result, and much that we prize will disappear in the desolation of new battles. Science may be called the flame of western civilization. The excrescences that frighten pessimistic critics—overcrowded cities, unpleasant working conditions, over-emphasis on mechanized pleasures, the growing possibilities of destruction in war—these are only the smoke. As a rule, smoke results from too little flame rather than from too much. This metaphor may be ended with these lines of Mr. George Russell—

> "We must pass like smoke, or live within the spirit's fire,
> For we can no more than smoke unto the flame return.
> If our thought is changed to dream, our will into desire,
> As smoke we vanish, though the fire may burn."

Defects in Timber Caused by Insects May be Largely Prevented. (U. S. Department of Agriculture, Press Service.)—Defects in timber caused by wood-boring beetles and grubs cause serious losses either by rendering the affected material unfit for use or by reducing it to lower grades. Insect damage to cut timber and lumber is even greater than that of standing timber, but much of this loss is preventable. Prevention consists chiefly in adopting proper methods of lumbering and management. This would usually involve but slight changes or modifications in present methods of handling the timber.

Department Bulletin 1490-D, "Defects in Timber Caused by Insects," just issued by the department, presents facts which will aid in determining the nature and cause of defects, gives recommendations for avoiding preventable injury, and discusses the types of defects which are not preventable. The principal damage comes under two types of defects, designated as wormholes, with no living worms or decay, and powder post. Powder post occurs only in the seasoned or partially seasoned sapwood or heartwood. This type of injury is dangerous, since the grubs continue their destructive work in the wood and also infest other timber near by.

Methods to adopt in reducing the losses from powder post depend on which species of insect does the damage. Four or five different ones are listed in the bulletin as causing this type of defect. In some cases the practice recommended is to treat finished wood products with substances such as paraffin wax, varnish, or other fillers which will close the pores and prevent egg laying. Effective remedies include kiln-drying at high temperatures; steaming at 130° F.; and treatment with a mixture of kerosene and coal-tar creosote, after which the material should be kept in quarantine. Submerging the logs in the mill pond and prompt utilization will prevent much loss from attack by some insects.

In the case of wormhole type of defects, caused in the tree, log, or green lumber before the wood is dry or seasoned, much waste can be avoided by utilizing the affected material for other uses and in lower grades than originally intended.

Special reference is made in this bulletin to the protection and conservation of both crude and finished wood products, such as lumber, bolts, cooperage stock, agricultural implement handles, tent poles, vehicle parts, timber for ship building, oars, airplane stock, and other high-grade products.

Occurrence of Racemic Lysine in Nature.—S. B. SCHRYVER and H. W. BUSTON (*Proc. Royal Soc.*, 1927, *B*, **101**, 519–527) report that *dl* lysine, the racemic isomer of lysine or alpha-epsilon-diaminocaproic acid, occurs in certain proteins, and is liberated only by the action of acids in the cold. J. S. H.

ON ELECTRETS.

BY

EDWIN P. ADAMS, D.Sc.

Professor of Physics, Princeton University;
Member of the Institute.

BARTOL RESEARCH FOUNDATION
Communication No. 16.

IT HAS been shown by Eguchi [1] that if mixtures of certain waxes are allowed to solidify from a molten state in a strong electric field, there appear to result permanently polarized dielectrics. For a permanently polarized dielectric, Heaviside proposed the name "electret," [2] in analogy with the name "magnet" for a substance with a permanent magnetic polarization.

It is natural to assume that when an electric field is applied to a melted substance, the molecules, or clusters of molecules, supposed to contain electric doublets, orient themselves with their axes in the direction of the electric field; on solidifying, the molecules, no longer mobile, keep their orientation, and there results a permanent electric polarization. This suggests the explanation that Lord Kelvin gave to account for the phenomenon of pyro-electricity. Certain substances, like tourmaline and quartz, which crystallize in asymmetric forms, always appear to be electrically polarized immediately after their temperature is changed, the sign of the polarization depending upon whether their temperature is raised or lowered. A slab of such a substance, with two plane faces perpendicular to the electric axis, shows, when its temperature is different from that of the surroundings, equal and opposite electric charges on the two faces; these charges gradually disappear as the temperature falls or rises to that of the surroundings. This phenomenon was explained by Lord Kelvin by assuming that the molecules of the substance are permanently polarized, the amount of polarization depending upon the temperature. As a result of this polarization, the two plane faces will have apparent electric charges, whose surface density is numerically equal to the electric moment per unit volume. If the substance itself, its surface, and the

[1] *Phil. Mag.*, **49**, p. 178, 1925.
[2] *Electrical Papers*, 1, p. 488.

surrounding air were perfectly non-conducting, these apparent charges could be detected by their external effects, just as the apparent magnetic charges, that result from magnetic polarization, can be detected. But because the electric resistance, although very large, is always finite, there will necessarily be a flow of electricity of opposite sign to the two plane faces of the slab, thus neutralizing the effect of the apparent charges, and the slab will appear to be non-electrified. If now the temperature of the slab be changed, on Lord Kelvin's hypothesis, the polarization, and consequently the apparent surface density, is immediately altered; as the conductivity is small, the compensating charges flow slowly, and so for a certain time, which may be some hours, the slab appears to be electrified.

The so-called permanent electrets of Eguchi differ in their behavior from these pyro-electric crystals in an important way. While the latter show no electrical effects after being kept at a constant temperature for a long enough time, the former appear to be permanently electrified. Eguchi reports that he has kept electrets for three years with no apparent diminution of their electrification. If the two faces of the pyro-electrical crystal, on the one hand, and the electret, on the other, are provided with conducting coatings, and these two coatings are electrically connected, the effect is the same, except for complications that result from residual charges, as if the compensating charges were formed almost immediately. If now the connection between the two faces is broken, the difference in behavior between the pyro-electric crystal and the electret is very striking. If the temperature remains uniform, the pyro-electric crystal shows no evidence of electrification; the wax electret, however, even if at the same temperature as its surroundings, becomes electrified gradually. The equal and opposite free charges on its two faces increase from zero, at the instant when the electrical connection between the two electrodes is broken, to a maximum value. At room temperature, it is this maximum value that appears to be constant, no matter how often the surfaces are discharged by connecting together the two electrodes.

In order to account for this phenomenon, which does not appear in the pyro-electric crystals, it seems necessary to suppose that the polarization of the electret is not constant, at a given temperature, but decays gradually, and so slowly at room tem-

peratures, that the diminution of polarization cannot be observed even over a period of some years. It will be shown later that this assumption of a very slow rate of decay is quite consistent with the requirement that it is the decay of the polarization that supplies the free charges that are observed.

Let then, at any instant, P be the electric polarization, defined as the electric moment per unit volume, of the electret. We suppose, first, that everything is at a uniform temperature, so that there are no pyro-electric effects to be observed. Let us assume that the decay of polarization follows the law of monomolecular reactions, such as is observed in the decay of radioactive substances. Thus we assume that

$$\frac{dP}{dt} = -\lambda P, \tag{1}$$

where λ is a constant at a given temperature, but will be supposed to increase rapidly with increasing temperature, as it does in chemical reactions, as distinct from radio-active transformations. From (1) we have

$$P = P_0 e^{-\lambda t}, \tag{2}$$

if P_0 is the value of the polarization at the instant $t = 0$. Let us fix our attention on that surface of the electret where the surface density of the apparent charge is $-P$; this is the surface that was positively charged during the formation of the electret. Let σ be the surface density, at any instant, of the compensating charge, and η that of the free charge on this surface. Then

$$\eta = \sigma - P,$$

or

$$\frac{d\eta}{dt} = \frac{d\sigma}{dt} - \frac{dP}{dt}. \tag{3}$$

Take $t = 0$ as the instant when electrical contact is broken between the two surfaces of the electret. Then when $t = 0$, $\eta = 0$. Now $\frac{d\sigma}{dt}$ is a measure of the current that flows to this surface. So we put

$$\frac{d\sigma}{dt} = -\beta\eta \tag{4}$$

where β is a coefficient whose reciprocal is the relaxation time of the electret regarded as a condenser, and depends upon the

volume and surface conductivities of the electret, as well as upon its dielectric constant. If there were no surface conductivity, the value of β would be $4\pi/K\tau$, where K is the dielectric constant and τ the specific resistance of the substance of the electret. The effect of surface conductivity is to increase the value of β. We now get from (3), using (1), (2), and (4),

$$\frac{d\eta}{dt} + \beta\eta = \lambda P_0 e^{-\lambda t}.$$

The solution of this differential equation that satisfies the condition $\eta = 0$ when $t = 0$ is

$$\eta = \frac{\lambda P_0}{\beta - \lambda}\left(e^{-\lambda t} - e^{-\beta t}\right). \tag{5}$$

At moderate temperatures we know that the polarization of the electret is nearly constant for long periods of time, and therefore λ is very small compared with β; we can therefore write, approximately, for small values of t,

$$\eta = \frac{\lambda P_0}{\beta}\left(1 - e^{-\beta t}\right). \tag{6}$$

Now it is η, the surface density of the free charge, that can be measured. Then from the way in which the free charge increases with the time, it should be possible to determine the values of β and λP_0 separately, but not the values of λ and P_0 separately. Thus we have,

$$\left(\frac{d\eta}{dt}\right)_{t=0} = \lambda P_0, \tag{7}$$

$$\log \frac{d\eta}{dt} = \log \lambda P_0 - \beta t, \tag{8}$$

while the maximum value of η is given by

$$\eta_{\max.} = \frac{\lambda P_0}{\beta}. \tag{9}$$

The simple theory that has been given applies to an ideal substance; the substances that are used in experiments, mixtures of different waxes in this instance, are far from having ideal properties. And it is hardly to be expected that the results obtained with these substances, whose physical properties can be only imperfectly defined, will be in quantitative agreement with any

such simple theory. In particular, the coefficient β has been supposed to be a constant at a given temperature. But we know from the anomalous behavior of the conductivity of imperfect dielectrics that this coefficient is certainly far from having a constant value. Part of the conduction is over the uncoated surfaces of the dielectric, and so the state of these surfaces will affect the value of β. During the course of the experiments, it has been frequently observed that cracks have developed along the edges of the electrets; internal cracks probably develop as well; this may account for some of the discontinuous changes that have occasionally been observed during a series of measurements.

In order to account for the anomalous dielectric properties of imperfect dielectrics, v. Schweidler[3] assumes that their molecules contain electric doublets that act as resonators. By assuming different kinds of doublets he obtains a fairly satisfactory account of some of these anomalous effects that are observed. So in the waxes that are used in preparing the electrets, it would probably be more reasonable to assume different kinds of doublets, each kind having its own constant of decay, λ. Therefore in equation (2), the right-hand side should be replaced by a sum of terms of the type that is written. But in view of the fact that the chemical composition of these waxes is not exactly known, and from what has been said of the variability of the coefficient β, it is hardly worthwhile to introduce this additional complication; all that can be hoped for at present is to get a general account of the principal effects that have been observed in the experiments about to be described.

Instead of electrets in the form of discs, with coatings of tinfoil on their two faces, as used by Eguchi, cylindrical electrets have been used in these experiments. Two thin-walled brass tubes were held, one inside the other, coaxially, in a bakelite form, and the melted wax, at a temperature of about 125° C., was poured into the space between them. The waxes had the following approximate composition:

	Per cent.
Carnauba wax	45
White resin	45
White beeswax	10

[3] *Ann. der Physik.*, **24**, p. 711, 1907. See also Wagner, *Ann. der Physik.*, 40, p. 817, 1913.

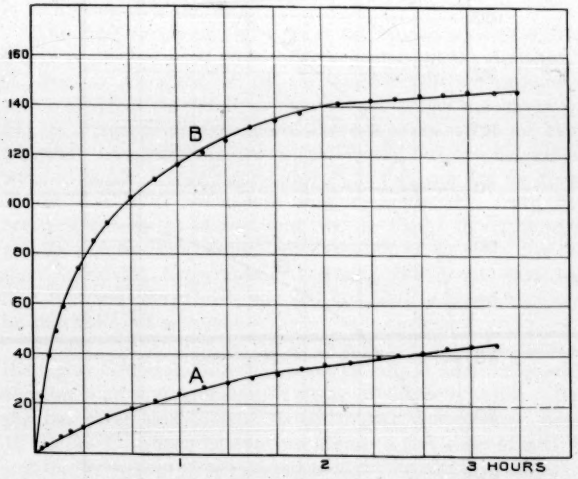
The brass tubes were 14 cm. in length; the outer one had an internal diameter of 2.4 cm., and the inner one an outer diameter of 1.9 cm., so that the thickness of the dielectric was 0.25 cm. They were warmed before the wax was poured in, and immediately afterwards they were connected to the terminals of a Kenetron rectifier; the difference of potential rose to about 4000 volts when solidification occurred. The current entered the inner cylinder and left the outer cylinder. This current was measured by a micro-ammeter; it fell from a value of about 10^{-4} amperes while the wax was melted to zero when the wax was hard. No attempt was made to measure the small current passing through the wax when it was cold. After the wax had hardened, the electret was taken out from the bakelite form, and the inner and outer cylinders were left connected for some time before any measurements were taken.

In order to measure the rate of change of the surface density of free charge on the surface of the electret, at a constant temperature, the electret was supported inside a brass tube, whose lower end was closed, and the whole placed in an electrically heated thermostat, filled with oil, whose temperature could be kept constant within about 0.2° C. The outer cylinder of the electret was connected to earth. A central electrode whose length was 7 cm. and diameter 0.6 cm., supported on a quartz rod, was held inside the inner cylinder, along its axis, and this electrode was connected to one pair of quadrants of an electrometer. This central electrode, while in contact with the electrometer, could be lifted out of the electret, and so the charge induced on it could be measured. From the rate at which electricity flowed into the electrometer with the central electrode in position, the rate $d\eta/dt$, of production of free charge on the surface of the electret, could be determined; η itself, at any time, was proportional to the deflection of the electrometer when the central electrode was raised, the earth connection to the electrometer having been broken at the given time. The electrometer, which was of the Dolezalek type, had a sensitivity of about 675 divisions per volt. A mica condenser could be connected to the insulated pair of quadrants of the electrometer in order to keep the deflections on the scale in measuring the larger values of the free charge.

Curve *B*, in Fig. 3, shows the way in which the free charge on the surface that was positively electrified during the formation

of the electret rises with the time, after the inner cylinder is insulated, and the electret is kept at a moderate temperature, 27° C. in this case. The ordinates are scale deflections of the electrometer, with a capacity of 0.001 microfarad connected to it. According to the simple theory, the free charge should rise in the way given by equation (6). But no single exponential curve of this type can be found to fit the observations at all well.

FIG. 1.

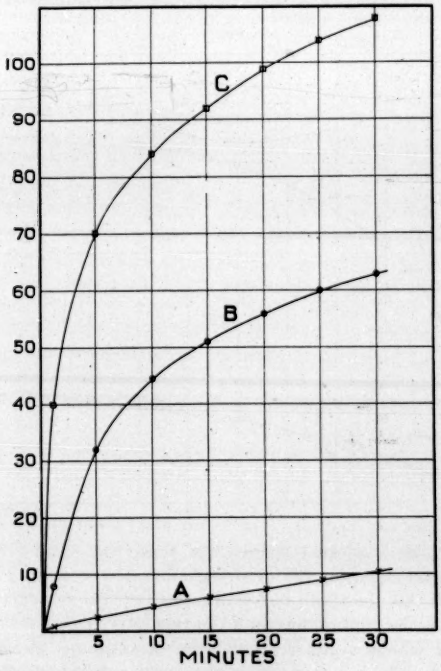


If log $d\eta/dt$ is plotted against the time, the result should be, according to equation (8), a straight line whose slope is β. But instead of this the result is found to be a curve. A curve whose equation is the sum of terms of the type of (6) could, of course, be found which would represent the observations as closely as one could wish, but there is no particular interest in attempting this. The results are given for observations extending over five hours. After about twenty-four hours from the beginning of the observations, the deflection of the electrometer had risen to 220, and this seemed to be very nearly the maximum value, although when the condenser was removed and $d\eta/dt$ measured

directly, it still had a very small positive value. While it is not of much significance, it is of some interest to determine an average value of β from this curve. The result is approximately $\beta = 0.22$, with the hour as the unit of time.

The effect of higher temperatures on the growth of the free

FIG. 2.



charge is illustrated in Fig. 1; curve *A* corresponds to a temperature of 35° C., and curve *B* to a temperature of 41° C. These curves show that the maximum value of the free charge is reached much quicker at the higher temperatures, and that the stationary values of the free charge increase rapidly with the

temperature. The interpretation of these results, according to the simple theory, is, first, that β increases with the temperature, resulting in a more rapid approach to the stationary value, and, second, that λ also increases with the temperature, but at a more rapid rate than β, so that the maximum value of the free charge, given by equation (9), is greater at the higher temperature. These two curves correspond to the same electret; a condenser of capacity 0.01 microfarad was connected to the electrometer in both cases.

The three curves in Fig. 2 show the way in which the free charge begins to rise at three different temperatures; *A* at 32.5° C., *B* at 40° C., and *C* at 49° C. These results were obtained with a different electret from the one used to get the curves of Fig. 1; a capacity of 0.01 microfarad was connected to the electrometer. According to the simple theory, λP_0 is the initial value of $d\eta/dt$. If we assume that P_0 is the same for the three curves, that is, if we assume that no appreciable decay has occurred during the observations, we see that λ increases very rapidly with the temperature, approximately in the ratio, for the three increasing temperatures, 1 : 8 : 40. But from what has been said, it is doubtful if any real quantitative significance can be attached to these numbers.

It was expected that the curves in Fig. 1, at least the curve at the higher temperature, would begin to fall, in accordance with equation (5), and so indicate a decay of the polarization. But this has never been found. At still higher temperatures, from 50° to 60° C., where the wax just begins to give signs of softening, the free charge rises to a maximum in the course of about an hour, and gives no indication of diminishing even after several hours. This result suggests that a process of ionization in these waxes may be an important factor in the production of the free charges that are observed, and so still further complicate the simple theory.

So far no direct evidence has been given of any decay of the polarization of these electrets. The most convincing evidence for the existence of electric polarization, aside from that given by Eguchi, will be given later, when their pyro-electric properties are described. That the polarization does decay, however, is shown by the fact that if an electret is kept at a fairly high temperature for some hours, with the two cylinders connected

together, and a second curve of the type shown in Fig. 1 is plotted, the maximum value of the free charge is distinctly less than before the long-continued heating. Furthermore, a few hours' heating at a temperature of 50° C. is sufficient to diminish the polarization so much that hardly any electrical effects can be observed when subsequent measurements are made at room temperature.

One electret was kept for thirty-five days continuously at a temperature of 40.5° C., with its inner cylinder insulated, and measurements were made of the free charge from time to time. The simple theory that has been given would lead one to expect that the polarization, and therefore the maximum value of the free charge, would diminish exponentially with the time. For, from equation (5) it is seen that η becomes proportional to $e^{-\lambda}$ when t becomes very large. The successive values of the free charge, while they did diminish on the whole, did so very irregularly, and did not fit any exponential curve. At the end of the thirty-five days the charge had fallen in the ratio 48:29. On leaving the electret short-circuited for a week, at the same temperature, there was a partial recovery to a ratio 48:40. If we assume this to represent a decay in the polarization, the value of λ would be about 2×10^{-4}, with the hour as the unit of time. This result is reasonable, for it shows that no sensible decay of the polarization can be expected in a few hours at this temperature. But, as in all of this work, little significance can be attached to any quantitative results.

We can conclude that a decay of the polarization does become evident at higher temperatures, although it has not been found possible to determine whether or not the dependence of the rate of decay upon the temperature is what might be predicted from a statistical treatment of the problem.

There remains the question as to whether the slowness of the rate of decay of the polarization is compatible with the magnitude of the free charges that are observed. Take 10^{22} as the order of magnitude of the number of molecules per unit volume of these waxes, and 10^{-17}, in electrostatic units, as the electric moment of each molecule. Then $P_0 = 10^5$. If the polarization does not diminish by more than 1 per cent. a year, λ must be less than 10^{-6}, with the hour as the unit of time. At a temperature of 20° C., β, for the cylindrical electrets, is probably much

less than 10^{-1}. So $\lambda P_0/\beta$, which is the maximum value of the surface density of the free charge, is of the order of magnitude of unity. This is much larger than the surface density has been found to be, at room temperature, on these cylindrical electrets, although for the disc electrets, Eguchi obtained surface densities as high as six electrostatic units. But it is probable that the effective value of β is much smaller for the disc electrets than for the cylindrical ones. It follows, therefore, that the rate of decay of the polarization may be sufficiently small so that the electrets will appear to be permanent for some years, and yet sufficiently large to account for the free charges that are observed.

THE PYRO-ELECTRIC EFFECT.

If these electrets are electrically polarized, as has been assumed, even if the amount of polarization does decay gradually, they should show pyro-electric effects, in accordance with Lord Kelvin's hypothesis. Consider an element of volume, dv, of the electret. Pdv is the electric moment of this element. Let the temperature rise $d\theta$ degrees. Then the volume becomes

$$dv' = dv\,(1 + \alpha d\theta),$$

where α is the coefficient of thermal expansion. Let $P + dP$ be the polarization at the higher temperature. Then

$$(P + dP)\,dv' = P\,dv,$$

or

$$dP = -\alpha P d\theta \cdot$$

It may be that there is a direct effect of temperature upon the polarization. In the case of pyro-electric crystals it is not certain whether the whole effect is a manifestation of the piezo-electric property of the crystals, or whether, in addition, there is a true pyro-electric effect. In any case, the influence of a change in temperature would be given by an expression of the form of (10).

We assume Newton's law of cooling to hold:

$$\frac{d\theta}{dt} = -\gamma\theta,$$

from which

$$\theta = \theta_0 e^{-\gamma t},$$

where θ_0 is the excess in temperature, over the surroundings, at the time $t = 0$. If the electret is initially cooled, then θ_0 is to be taken as negative.

The whole change in the polarization is now given by the sum of (1) and (10). We therefore have,

$$\frac{dP}{dt} = -\lambda P_0 e^{-\lambda t} + \alpha\gamma\theta_0 P_0 e^{-(\gamma+\lambda)t}.$$

It must be remembered that since, as has been shown, λ is a function of the temperature, and so of the time, this expression is only an approximation; for our purpose it will be sufficient to take a mean value of λ over the range of temperature concerned, and discuss qualitatively the effect of the progressive change in its value as the electret cools or warms to the surrounding temperature.

Equation (4), which gives the rate of change of surface density of the compensating charge, is, in the present case, also only an approximation. If we consider a surface element of the electret, there is a flow of electricity out of this element resulting from its surface expansion. But this effect, which is small compared with the effects retained, may be ignored for our purpose.

We finally get for the differential equation giving the surface density of free charge on the electret,

$$\frac{d\eta}{dt} + \beta\eta = \lambda P_0 e^{-\lambda t} - \alpha\gamma\theta_0 P_0 e^{-(\gamma+\lambda)t}.$$

Its integral, satisfying the condition $\eta = 0$ when $t = 0$, is

$$\eta = \frac{\lambda P_0}{\beta - \lambda}(e^{-\lambda t} - e^{-\beta t}) - \frac{\alpha\gamma\theta_0 P_0}{\gamma - \beta + \lambda}(e^{-\beta t} - e^{-(\gamma+\lambda)t}).$$

We know that λ is very small, so that we may write, as an approximation, until t gets very large,

$$\eta = \frac{\lambda P_0}{\beta}(1 - e^{-\beta t}) - \frac{\alpha\gamma\theta_0 P_0}{\gamma - \beta}(e^{-\beta t} - e^{-\gamma t}), \qquad (11)$$

and

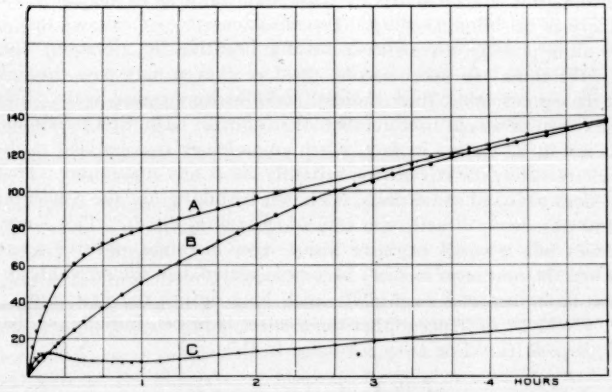
$$\frac{d\eta}{dt} = \lambda P_0 e^{-\beta t} + \frac{\alpha\gamma\theta_0 P_0}{\gamma - \beta}(\beta e^{-\beta t} - \gamma e^{-\gamma t}). \qquad (12)$$

It will now be shown that these expressions are sufficient to account qualitatively for the pyro-electric effects that have been observed in experiments with electrets. In order to make these experiments, the electret, with its two electrodes connected, was placed in a tube and immersed in a water-bath for about an hour,

at either a higher or a lower temperature than the thermostat in which it was afterwards placed. The surface density, η, of the free charge on the inner surface of the electret, or its time rate of change, $d\eta/dt$, was then measured, from time to time, just as in the experiments that have already been described.

In the case of pyro-electric crystals, it is known that the coefficient γ, which determines the rate of cooling or heating, is larger than the coefficient β, which determines the rate of flow

FIG. 3.



of the compensating charges. Except at the higher temperatures, where the waxes begin to soften, the same is true of these electrets; for the time required for the free charge to reach a maximum value is long compared with the time required for the electret to reach a stationary temperature. If, now, the electret is cooled initially, θ_0 is negative, and it follows from the expression (11) that the free charge on the face we are considering can never become negative; of course on the opposite face the free charge can never become positive. For the second term in the expression for η is always positive; starting from zero, it reaches a positive maximum, and then diminishes to zero again. This result has always been found. A typical example is given in curve *A*, Fig. 3. This curve was obtained for an electret

that had been cooled at about 1° C. for an hour, and then placed in the thermostat at 27° C. Curve *B* is for the same electret, after having been short-circuited for some hours and kept at the same temperature, 27° C. In both curves, the time $t = 0$ is the instant when the inner cylinder is insulated. The ordinates of all three curves, *A*, *B*, and *C*, to be described later, are actual deflections of the electrometer, with a capacity of 0.001 microfarad connected to it. It is seen that the effect of the initial cooling is to cause the free charge to rise more rapidly at first, although it tends towards the same final value as in the case when there is no initial cooling. Examination of (12) shows that it is quite possible for $d\eta/dt$ to become negative for a certain value of the time. In other words, the free charge may pass through a maximum value, then diminish, and finally increase again. This has been observed in a number of instances. The first maximum is not at all sharp; in fact, when a condenser is connected to the electrometer, the curves for η hardly show any maximum. That it does exist, in some cases, is shown by taking out the condenser and observing directly the rate of charging, $d\eta/dt$. This sometimes has a small negative value, then becomes positive again when the first term in (12) becomes greater than the second term; the latter becomes negligibly small long before the first term.

Now let us suppose that the electret is heated initially, so that θ_0 is positive. For $t = 0$, we have, in this case,

$$\left(\frac{d\eta}{dt}\right)_{t=0} = \lambda P_0 - \alpha\gamma\theta_0 P_0,$$

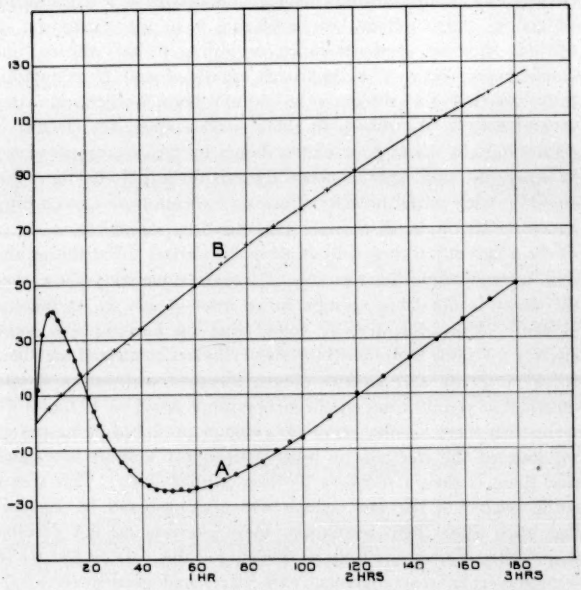
and this may be either positive or negative. For a pyro-electric crystal, where the first term on the right does not enter, this expression is of course negative. But for an electret, it has been found to be positive in every case, and, in fact, to be considerably larger than it is if there is no initial heating. The reason for this is that as a result of the initial heating, the term λP_0 is very much larger than it is without the initial heating, and even still larger than it is when the electret is initially cooled. It is so large, in fact, that the first rise of the free charge is more rapid than when the electret is not heated initially; in some cases, it is even more rapid than when the electret is cooled initially. After the first rise, the free charge reaches a first maximum in about eight or

nine minutes after insulating the inner cylinder; after this, it reaches a minimum value in fifty minutes or an hour; and finally the free charge begins to increase again towards a maximum which is greater than the first maximum. Curve *C*, in Fig. 3, illustrates these points. This curve was taken with the same electret, after curve *B* was taken, the electret having been short-circuited in the intervening interval; it was kept at a temperature of 40° C. for an hour before placing it in the thermostat at 27° C. For an ideal substance, according to this theory, one would expect curve *C* to approach curves *A* and *B* asymptotically, so that the three curves would become identical after several hours. As shown in these curves, when the electret is cooled initially, after four or five hours its free charge increases at nearly the same rate as when there is no initial cooling. But curve *C*, with initial heating, gives no indication of approaching curve *B*. It might be thought that this was a result of a decay of the polarization caused by heating the electret. But the results that were obtained on the effect of heating electrets show that the decay is not large enough in an hour at 40° C. to become evident. Moreover, it was found that on keeping this same electret for some hours with the two cylinders connected together, recovery set in, and a curve almost identical with curve *B* was obtained, a second time, at the temperature 27° C. It therefore seems that there is some temporary change produced in the physical state of the electrets by heating them for a short time, and that there is then a recovery to their former state. This seems to be related to the fact, which was also observed by Eguchi, that soon after their formation, these electrets do not develop their full polarization; time is needed for this. It is just as if some molecular rearrangement took place, analogous to recrystallization, after the electrets have solidified from a molten state, or even after having been merely heated, without melting. Or it may be that the presence of free ions in these electrets, and their gradual recombination, may be the cause of this phenomenon.

Equation (12) shows that it is possible for the electret to have a negative free charge on the surface that was positively charged during its formation, if the electret is heated initially, while we have seen that this surface can never get a negative

charge if the electret is initially cooled. Curve *A* in Fig. 4 illustrates this distinctly. This was obtained with an electret that had been heated to 40° C. for about an hour, and then placed in the thermostat at 25° C. As in curve *A*, Fig. 3, a positive maximum is reached in eight to nine minutes, followed by

FIG. 4.



a minimum, which in this case is negative, in about an hour from the time that the inner cylinder is insulated. Curve *B* is for the same electret after having remained at the temperature of 25° C. for two days with its two cylinders connected.

Freshly prepared electrets have never exhibited this negative minimum; in fact, they even show no initial maximum. Thus the process of settling down to a steady state is especially important for the development of the pyro-electric properties of these

electrets. The existence of these negative charges, even for a short time only, is fairly conclusive proof of the pyro-electric properties of electrets.

THE PIEZO-ELECTRIC EFFECT.

It is known that all pyro-electric crystals have also the piezo-electric property—the property of developing electric charges of equal amount and opposite signs when under a state of strain. And it has already been said that there is some evidence, although perhaps not conclusive, that the piezo-electric property is the fundamental one, while the pyro-electric effect results wholly from the strains set up by heating. However this may be, these electrets, having been shown to have the pyro-electric property, should also exhibit the piezo-electric effect. Only the roughest method has been used to show this effect. The electret was held in a clamp under moderate pressure; the outer cylinder was connected to earth, and the inner cylinder was insulated. An insulated central electrode, connected to the electrometer, was held axially inside the inner cylinder. On gradually increasing the pressure of the clamp, the electrometer received an increasing negative charge, showing that the inner cylinder became negatively charged as a result of the pressure; on releasing the pressure of the clamp gradually, the charge diminished to zero and changed in sign as the pressure became less than it was initially. There appeared to be no diminution of this effect on repeating the cycle over and over again. The effect is quite a large one, and from the ease with which these electrets can be made, and moulded in any form, it is quite possible that there may be a number of applications for them; in fact, they might be called artificial piezo-electric crystals.

SUMMARY.

(1) Evidence has been given that the so-called permanent electrets of Eguchi are not permanent, but that their polarization decays with the time. At room temperatures this decay is too slow to be observed directly; but it is the decay of the polarization that, at least in part, accounts for the presence of the free charges that are always observed. At higher temperatures the results that have been obtained are consistent with the view that

the rate of decay of the polarization increases very rapidly with the temperature; so much so that the polarization may be almost completely destroyed at a temperature which is not high enough to cause any appreciable softening of the waxes that form the substance of the electrets.

(2) As is to be expected from Lord Kelvin's hypothesis as to the cause of pyro-electricity, these electrets have been shown to possess the pyro-electric property.

(3) The piezo-electric effect, which always accompanies the pyro-electric property, has been shown to be exhibited by these electrets.

NEW TYPE OF LOW-VOLTAGE MERCURY ARC.

BY

ARTHUR BRAMLEY, Ph.D., and WAYNE B. NOTTINGHAM, B.S.

Bartol Research Fellows.

BARTOL RESEARCH FOUNDATION
Communication No. 17.

MERCURY arcs, in general, can be divided into two classes, those which depend for their primary cause of excitation on the thermionic electrons emitted from a heated cathode and those which are started by breaking the contact between two pools of mercury forming part of the electric circuit and whose mechanism of excitation subsequently is a matter of discussion at the present time. The first type is the one generally used in the investigation of the characteristics of the mercury arc, *i.e.*, potential gradients, electron concentration, etc., on account of the simplicity of the conditions at the cathode, the emission of thermionic electrons. The tubes used in the investigations are usually constructed with a tungsten filament, and a nickel anode, the evacuated space being filled with mercury vapor at a pressure corresponding to its vapor pressure at room temperature. The second type of discharge tube on account of the complicated conditions existing at the cathode and anode is not very suitable for experimental research, although it is rather interesting to note that in this type of arc the anode can be made of any conducting material without effect on the characteristics of the discharge but the cathode must always be mercury.

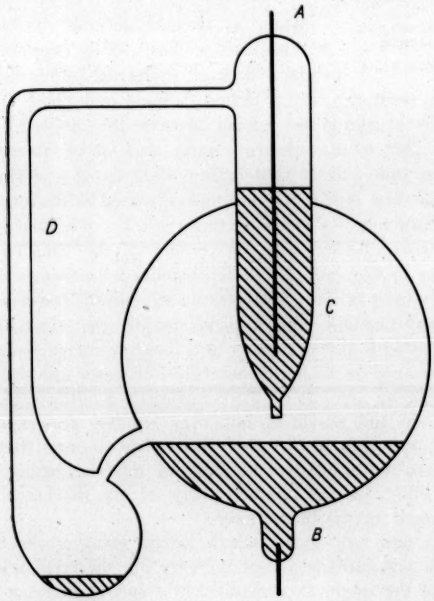
In the new type of arc which we are going to describe both the anode and cathode are of mercury but the conditions at the cathode or the anode are controlled by a special device, a mercury dropper, which simplifies the mechanism of the arc. A diagrammatical sketch of the design of the tube is shown in Fig. 1.

The tube, which is highly evacuated, contains two electric terminals A and B, which make contact with the two pools of mercury, the end of the vertical tube C is constricted and terminates in a small capillary tube, diameter .5 mm. approximately, which allows the mercury in C to drop slowly, one drop per second on the average, into the second pool connected with B electrically. The side tube D is used to replenish the supply of

mercury in C which gradually runs into B and to keep the mercury in the pool B at a constant level.

In the operation of the tube, the terminals A and B were connected to a battery and the reservoir C filled with mercury which runs through the capillary into B, A being the cathode and

FIG. 1.



B the anode of the tube. The voltage between A and B was gradually changed until the discharge commenced, which occurred in the vicinity of 425 volts with a current flow of one-half milliampere. As the voltage was increased the current varied with the applied potential according to the relation

$$i = A V^{n}$$

where i is the current, V the voltage, and A a constant depending on the design of the tube. The discharge in this case was a

deep red color, but the mercury drops were surrounded with a green haze which seemed to indicate intense ionization around them as they fell through the entire electric field. By using an oscillograph, arranged to measure the current-voltage characteristic of the discharge, oscillations of the same period as the falling drops were detected.

At sufficiently high voltages, however, the character of the discharge gradually changed at about 500 volts from the type described in the preceding paragraph to one where an intense discharge occurred whenever a drop fell, decaying to zero in the interval between successive drops; moreover, the glow in this case was the same as that associated with the mercury arc.

Using the mercury dropper as the anode, the voltage applied between *A* and *B* was slowly varied until the discharge started, which began at 300 volts, approximately. In operation the discharge showed a brilliant green corona around the tip of *C* but behind the falling drop, the drop itself as it fell through the discharge space showing a bright green haze around it, although the surface of the second pool—the cathode—appeared undisturbed. At a voltage of 320 the average current carried was 55 milliamperes for one design of tube, but the current fluctuated over a wide range due to the changing resistance of the tube. From observations with the oscillograph two types of oscillation were found, first a high-frequency oscillation of several thousand cycles per second, which could be detected by placing a telephone in series with the tube, and second an oscillation of large amplitude with a period corresponding to that of the cycle of the falling drops. Under certain conditions the amplitude of this oscillation varied from zero to a maximum value which depended on the construction of the tube, the high-frequency oscillations occurring in the region of the peak current.

The observations of this type of discharge seem to indicate that the primary mechanism of the discharge may be due to one of the two following types of phenomena or even to both acting simultaneously:

(1) Ionization of the gas in the neighborhood of the falling charged drops as they change their electrical energy by falling through the potential gradient.

(2) Electric discharge between the charged mercury drop and the column as the drop is being severed from the capillary

or just after it has parted and fallen through the cathode or anode potential gradient.

In this paper, a new type of mercury cathode or anode is described which consists essentially of a device for allowing mercury droplets to fall from one mercury reservoir, the cathode or anode as the case may be, to another used as the anode or cathode. When the potential difference between the cathode and anode is sufficient, in the tube described above 300 or 400 volts according to the direction of the applied field, a discharge commences whose current fluctuates with the same period as that of the falling drops, as the resistance of the tube decreases markedly each time a drop falls through the field. The falling drops are also surrounded by a bright mercury glow, showing that intense ionization occurs around the surface of the drop.

In conclusion, the authors wish to express their indebtedness to Prof. K. T. Compton, of Princeton University, for the loan of the oscillograph which was used in this investigation.

THE PREPARATION AND PROPERTIES OF SOME SYNTHETIC PHOTOHALIDE EMULSIONS.*

BY

E. P. WIGHTMAN, A. P. H. TRIVELLI and S. E. SHEPPARD.

(With experimental work by F. G. Keenan.)

THE object of the present work was the preparation of synthetic "photohalide" emulsions to be used in a study of photographic reversal and of the Herschel effect. The work is very incomplete, but certain results obtained seemed to warrant publication, since they have a direct bearing on the theory of the chemical sensitizing of photographic emulsions.[1] The emulsions studied are very slow compared with commercial emulsions and, therefore, have no practical value.

The preparation of a synthetic photohalide emulsion involves the precipitation of silver halide in the presence of colloidal silver. The colloidal silver particles may serve as nuclei for precipitation and are also adsorbed to the silver halide grains during their growth. In other words, they are in the same intimate contact with the silver halide crystals as the silver formed by photochemical decomposition would be.

Previous experiments on the preparation of colloidal silver and synthetic "photohalides" were recorded by Carey Lea and later by Lüppo-Cramer,[2] who also gave a very complete résumé of the former's work.[3] These served as a starting-point for the experiments described below.

EXPERIMENTAL.

The Preparation of Colloidal Silver.—Numerous methods might have been utilized in the preparation of colloidal silver, but Carey Lea's ferrous citrate method was first attempted.

* Communication No. 309 from the Research Laboratory of the Eastman Kodak Company.

[1] S. E. Sheppard, *Colloid. Symp. Monog.*, **3**, 76 (1925); *Phot. J.*, **65**, 380 (1925); *Brit. J. Phot.*, **73**, 33 (1926); *Phot. J.*, **66**, 505 (1926); Sheppard and Wightman, paper sent for publication.

[2] Lüppo-Cramer, "Kolloidchemie und Photographie," 2nd Aufl., Theo. Steinkopff, Dresden, 1921; various papers in *Phot. Korr.*, 1889 and 1907–1909.

[3] "Kolloides Silber und die Photohaloide von Carey Lea," Neuausgabe von Lüppo-Cramer, Dresden, 1908.

According to it silver nitrate is reduced by slightly alkaline ferrous citrate giving a deep red-brown solution of colloidal silver which is stabilized by precipitating the silver with 6 per cent. ammonium sulphate solution and washing repeatedly with this until iron is removed, followed by washing with alcohol. Centrifuging could not be used to hasten the washing procedure since the silver once packed at the bottom of the centrifuge cup could not then be completely dispersed again.

On attempting to use, in the making of emulsions, the silver thus prepared, it was found very difficult, if not impossible, to obtain a stable emulsion. The principal disadvantage of the method lay in the ease of coagulation of the colloidal silver, and variation of various factors did not seem to obviate it.

Carey Lea's dextrin method was then tried, since according to him it gave a very stable colloid, comparatively insensitive to the presence of salts or to heat. The results obtained were in agreement with this. The following is a slight modification of the Carey Lea directions:

> In 1800 c.c. of distilled water, 40 gms. each of sodium hydroxide and of yellow dextrin were dissolved. To this solution were added slowly, taking about five minutes, 28 gms. of silver nitrate dissolved in 100 c.c. of water. Both solutions and the mixture were held at a temperature of 15–20° and the mixture was stirred vigorously until at least ten minutes after the final addition of silver nitrate. A mechanical stirrer was used. The color of the resulting colloidal silver sol was similar to that of a heavy lubricating oil. The sol contained a little less than 1 per cent. of colloidal silver.

In the first experiments the silver sol was freed of most of the salts and alkaline dextrin by precipitating and washing the silver with alcohol and resuspending in distilled water, but it was soon found that the absence of these, particularly of the dextrin, was detrimental, rather than otherwise, to the preparation of a stable emulsion, possibly due to decreased dispersion of the silver. In the later experiments, therefore, they were allowed to remain at least until the emulsion was formed.

The Formation of the Photohalide Emulsion.—Attempts to prepare the "photohalides" by the original formulas of Lüppo-Cramer were all failures. This was primarily due to the fact that they called for the use of purified colloidal silver and that the amount of ammonia recommended was either too high or insuffi-

cient, depending on whether the chloride, bromide or iodide was being formed.

After numerous trials and failures to obtain a stable emulsion, the concentrations of gelatin, of colloidal silver and of the ammonia and sulphuric acid used being varied separately, the following formulas and procedure were worked out and the emulsion so prepared was found to remain in suspension very satisfactorily.

Solution *A*	2.5 gms. gelatin in 100 c.c. H_2O
	10.5 gms. KBr in 50 c.c. H_2O
	7.0 c.c. H_2SO_4 (conc.)
Solution *B*	15.0 gms. $AgNO_3$ in 100 c.c. H_2O
	17.5 c.c. NH_4OH (sp. gr. 0.91)
	100.0 c.c. colloidal Ag (1% unpurified)
Solution *C*	30.0 gms. gelatin in 100 c.c. H_2O

The bromide solution, *A*, is heated to approximately 60°, while the silver nitrate solution, *B*, is used at room temperature. Both solutions are poured simultaneously into a third beaker, taking care that the ammoniacal solution, *B*, is always slightly in excess, thus forming the emulsion in an alkaline medium. The combined solutions are thoroughly mixed either by a mechanical agitator or by pouring back and forth several times from one beaker to another. Finally, the gelatin solution, *C*, is added and the emulsion is ripened one hour at 60°. The emulsion should have throughout the ripening process a very faint odor of ammonia. If not, a drop or two should be added. Wratten Series 3 safelights were used to illuminate the room in which the emulsions were made.

The relative concentrations of sulphuric acid and ammonia used in the initial solutions control the color of the photohalide produced. The greater the excess of ammonia above the acid equivalence, the less intense the color of the final product, and also, the greater the amount of ammonia above a certain very slight excess, the greater the instability of the emulsion. An acid photohalide has an intense color and increases in instability as the acidity is increased; more so with the iodide than with the bromide, and this in turn to a greater extent than with the chloride. The acid or the alkali first of all tends to coagulate the colloidal silver, and subsequently the silver halide.

Since the solubilities of the silver halides in ammonium hydroxide are in the decreasing order chloride > bromide > iodide, the peptizing action of the ammonia would no doubt follow the same order and hence a greater excess of ammonia should be required to peptize the iodide than the bromide or chloride. This was tested qualitatively and found to be the case. Since only

slight variations in the concentration of ammonia have a very strong influence on the photohalide emulsion, more careful investigations along this line are desirable.

It should be noted that ammonia apparently has a specific action not evidenced by other alkalies, *i.e.*, it cannot be replaced by them.

The amount of colloidal silver in the emulsion does not affect its stability but has an important bearing on its later properties, and the ease with which an excess of it can be removed must be considered. This will be discussed presently.

In most of the experiments the emulsion was coated on plates before washing or removal of excess silver, although some trials were conducted on putting into the emulsion in the first place such a small amount of colloidal silver that there would be no excess to remove. This was quite successful when the amount of silver sol used was 1 c.c. instead of 100 c.c., as in the formula above, but the photographic characteristics of the emulsion were quite different from those prepared in the other way.

Coating and Washing the Emulsion.—Without allowing the emulsion to set after ripening, it was usually coated at 40° on 12.7 × 17.8 cm.^{2} glass plates. The plates were placed on a level platform while coating. On chilling, the emulsion set very quickly. The plates containing the set emulsion were then placed in running ice water for thirty minutes and were next hardened in a 1 per cent. chrome alum solution, and washed again and dried.

Removal of Excess Colloidal Silver.—The emulsion thus prepared had a chocolate color, but if some oxidizing agent such as a few drops of nitric acid in excess of the free ammonia equivalence were added, the silver remaining in suspension and not absorbed to the grains was dissolved, leaving a violet- or lilac-colored photohalide, the color of which was not affected by further addition of the acid.

Removal of the excess silver from the emulsion is necessary if the latter is to be of any use, since, as first prepared, the emulsion is usually developable without the action of light.

A solution of the oxidizing agent either may be added to the fluid emulsion, or the plates after coating may be bathed in it. The former method is preferable, of course, provided the excess desensitizer and the decomposition products can be eliminated, because it is simpler and the effect more uniform.

An attempt was made to remove the excess colloidal silver from the emulsion with permanganate before coating, following this by a treatment with oxalic acid and manganous sulphate to destroy excess permanganate and manganese dioxide. This was unsuccessful, the emulsion after coating fogging badly on development without exposure.

For removing the excess of silver from the plate a bath in chromic acid was given. The method was similar to that used previously [4] in experiments on desensitizing. Other oxidizing agents were tried but did not give as clean fog-free plates as the chromic acid. The excess of the latter was removed by bathing the plates in bicarbonate solution followed by acetic acid solution and washing. Of course, this treatment removes much of the original sensitivity. Indeed, the first plates so prepared were exceedingly slow in speed. It was this fact which led to the already mentioned experiments on decreasing the amount of colloidal silver used in making the emulsion. Also other emulsions were made increasing the temperature of the solutions before mixing and during the time of ripening. In addition a slightly greater amount of ammonia in solution *B* and a less amount of sulphuric acid in solution *A* were used. By this procedure a more sensitive emulsion was obtained. It was not expected that an especially rapid emulsion would result.

The Method of Exposing and Developing.—Plates were exposed behind an Eder-Hecht graded step tablet with a so-called neutral gray portion down the centre and blue, green, yellow, and red filters down each side. The light source was an opal glass aperture, illuminated in a lamp house by a 900-w., 30-amp. motion picture projection lamp run at 29 amps. The opal glass was a metre from the wedge and the exposure time in most cases was one minute. Development was carried out as for ordinary plates, in a pyro-soda negative developer [5] for five minutes at 18°. Fig. 1 shows an example of a typical result obtained with such an emulsion. Print 1 was obtained from a plate exposed as above and 1*A* shows the result when the exposure was made behind the Eder-Hecht wedge to sunlight. Notice in the latter

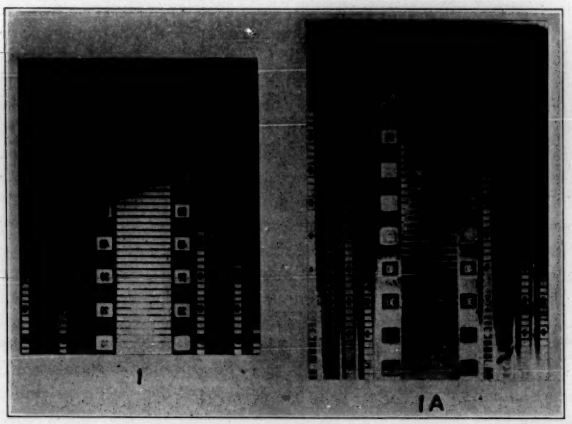
[4] S. E. Sheppard, E. P. Wightman and A. P. H. Trivelli, JOUR. FRANK. INST., **196**, 779, 802 (1923); *Ibid.*, **198**, 507 (1924).

[5] E. P. Wightman, A. P. H. Trivelli and S. E. Sheppard, *J. Phys. Chem.*, **27**, 41 (1923).

the strong reversal and in both cases the fairly high sensitivity to yellow and red compared with the blue, but the very weak sensitivity to the green in comparison. These phenomena seem to be characteristic of most of the "photohalide" preparations. The panchromatism of photohalide emulsions was noted years ago by Lüppo-Cramer and others.

There was one marked exception. The emulsion prepared

FIG. 1.



Normal exposure. Exposed to sunlight, one minute.

Photohalide emulsion precipitated at 70° and ripened one hour at 60°, slightly ammoniacal throughout.

using a small amount of colloidal silver and no chromic acid treatment, although having a higher sensitivity relatively in the blue showed very little, if any, yellow and red sensitivity and no reversal or solarization under similar conditions.

A very interesting fact is that when an emulsion was prepared using colloidal silver sulphide in place of silver (1 c.c. of a 0.05 per cent. solution in the above formula) and the excess, if any, was not removed, the speed was equal to that of a parallel silver "photohalide" and while it did not show reversal as did the latter, it had also a comparatively high sensitivity in the yellow and red.

Resensitizing CrO_3-desensitized Plates.—An attempt was made to bring back some of the sensitivity lost when excess silver was removed by chromic acid treatment. Treatment of the plate with varying dilutions of ammonia solution revealed the fact that with a 1 to 20,000 ammonia solution containing 0.1 per cent. potassium bromide applied for one minute, a CrO_3-treated plate could be raised in sensitivity about 100 times. Sodium thiosulphate of the same strength caused serious latent fog, and increased the speed only about twenty-five times.

DISCUSSION.

In a recent paper by the authors,[6] it was noted that plates bathed in a chemical sensitizer such as allyl-thiourea to produce silver sulphide specks on them, showed a comparatively high green and yellow sensitivity, and very slight red sensitivity compared with the blue. In the above cases where the sensitizing material is present during their formation, the yellow and red sensitivity are high comparatively, and there is very little sensitivity to the green. The work so far in both cases was only preliminary, and so before attempting any explanation of this difference we desire to examine it more carefully and systematically.

Trivelli previously suggested[7] that strains existed in the silver halide lattice containing silver iodide which increased sensitivity. Sheppard, Trivelli, and Loveland have extended this hypothesis of sensitivity[8] and the present work seems to be in harmony with it. They considered that there is ionic deformation in the neighborhood of the sensitivity speck caused by the speck itself. This strain and deformation may in themselves cause a change in optical sensitivity.

Presumably the colloidal silver or silver sulphide particles, acting as nuclei for deposition of the silver halide grains, could also create deformations of contiguous ions.

Whether or not the optical sensitizing is due to the speck material itself acting as a partial absorber of the light and passing on energy to the silver halide, or to strain and ionic deformation

[6] S. E. Sheppard, A. P. H. Trivelli and E. P. Wightman, paper sent for publication.

[7] A. P. H. Trivelli, *Archiv. Neelandaises d. Sci. Ex. et Naturelles*, (II) **14**, 339 (1909).

[8] S. E. Sheppard, A. P. H. Trivelli, and R. P. Loveland, JOUR. FRANK. INST., **200**, 51 (1925).

has so far not been definitely decided, although Sheppard, Trivelli and Loveland,[8] and Sheppard [9] have pointed out some evidence against the former view.

BEARING ON THEORY OF PHOTOGRAPHIC SENSITIVITY.

As stated, the emulsions described were prepared for other purposes than testing sensitization theories. The results, however, have some bearing on these. Thus the roughly parallel behavior of colloidal silver and colloidal silver sulphide shown in

TABLE I.

Comparison of Emulsions Prepared and Treated in Various Ways.

	Emulsion.	Treatment.	Blue Sensitivity.	Color Sensitivity.	Reversal.
A	100 c.c. colloid Ag used	CrO_3 extracted	Good 85° E.H.	Marked	Marked, up to 50° E.H. in sunlight.
B	1 c.c. colloid Ag used	No extraction	Good 100° E.H.	Little	No reversal under same conditions.
C	1 c.c. colloid Ag_2S	No extraction	100° E.H.	Marked	No reversal.
D	100 c.c. colloid Ag	CrO_3 extracted sensitized with 1:20,000 ammonia	30 to 100 times A	.....	.....

one experiment is interesting as showing these to be equivalent to a certain degree in fine-grained, low-speed emulsions.

Again, the difference between emulsions made with very little colloidal silver and no extraction, from those made with much colloidal silver followed by extraction, seems significant.

It apparently indicates that in panchromatizing by colloidal silver, as well as in facilitation of reversal (and Herschel effects), the completely protected colloid silver amicrons are less effective than the more superficial unprotected silver nuclei which are also effective for blue-violet sensitization. Further, the sensitization by small amounts of ammonia after chromic acid extraction probably peptizes the surface and lays bare interior nuclei, possibly also changes their dispersity, and thus produces increased sensi-

[9] S. E. Sheppard, *Coll. Symposium Monog.*, 3, 76 (1925).

tivity. This is in line with Lüppo-Cramer's investigations on "Keimblosslegung." [10]

The question as to how far silver nuclei can replace, or supplement, silver sulphide nuclei in high-speed negative emulsions is not touched by these experiments, and is being investigated separately. The results may be interpreted as showing that halogen acceptance is not a necessary function of sensitizing sulphide nuclei [11] inasmuch as silver can replace them in these emulsions, but that does not, therefore, exclude the hypothesis for high-speed, coarse-grained emulsions.

SUMMARY.

(1) A method of preparing photohalide emulsions somewhat different from that of Lüppo-Cramer has been worked out, using either colloidal silver or colloidal silver sulphide as the sensitizer.

(2) Treatment of the plates containing this emulsion with chromic acid to remove excess colloidal silver also lowers sensitivity considerably. This sensitivity can be restored by an after-treatment of the plates with a very dilute ammonia solution.

(3) The photohalide emulsion prepared as described showed, with one exception, a broader spectral sensitivity than those prepared without colloidal silver or silver sulphide. This agrees with the previous work of others on photohalide emulsions.

(4) The spectral sensitivity of such emulsions differs from those sensitized with allyl-thiourea sensitizer in being more sensitive in the red and less sensitive in the green region of the spectrum.

(5) The present work supports the strain-ionic deformation hypothesis of sensitivity proposed by Sheppard, Trivelli and Loveland. It does not, however, exclude the hypothesis of Hickman as to the rôle played by the silver sulphide sensitizing speck.

[10] *Cf.* J. M. Eder's "Hdbuch. d. Phot.," Bd. IV (new edition by Dr. Lüppo-Cramer, 1926, W. Knapp).

[11] K. C. D. Hickman, *Phot. J.*, **67**, 34 (1927).

Sunlight-stable Silver Halides.—PELL BROADY and C. B. JORDAN, of Purdue University (*Jour. Am. Pharm. Asso.*, 1927, **16**, 425–430), have prepared dilute colloidal suspensions of the silver halides which are stable in sunlight, *i.e.*, the silver compounds are not decomposed by the light. Silver oxide was precipitated by means of an excess of sodium hydroxide in the presence of gelatin. The oxide was then reduced to the metal by addition of formaldehyde. This preparation was treated with an aqueous solution of iodine and potassium iodide (Wagner's reagent) to obtain colloidal silver iodide. When an aqueous solution of bromine and potassium bromide was used instead of Wagner's reagent, colloidal silver bromide was obtained. When a solution of dichloramine T was used instead of Wagner's reagent, and the reaction was carried out at the temperature of the water bath, colloidal silver chloride was obtained. J. S. H.

Volumetric Determination of Phenols and Aromatic Amines by Means of Bromine.—ALLAN R. DAY (*University of Pennsylvania Thesis*, 29 pages, 1927) has applied the procedure of Koppeschaar (use of a standard bromine solution) to the volumetric determination of a number of phenols and aromatic amines. The organic compound is dissolved in water if soluble in that compound; otherwise, dilute sodium hydroxide solution is used as the solvent for phenols, and dilute hydrochloric acid as the solvent for amines. The titration may be made by either the direct method or the excess method. In the *direct* method, the solution of the organic compound is mixed with an aqueous solution of potassium bromide and then acidified with concentrated hydrochloric acid; the titration is then made with a fifth normal solution of potassium bromate, using potassium iodide-starch paper as an external indicator. In the *excess* method, the fifth normal "bromine" solution contains 75 grams of potassium bromide and 5.6 grams of potassium bromate in 1 litre. The solution of the organic compound is mixed with a definite volume of this bromine solution; unless the compound is subject to oxidation, the quantity of bromine used is approximately twice that required to brominate the compound. Concentrated hydrochloric acid is then added; in the presence of this acid, the bromide and the bromate react to liberate bromine which then brominates the organic compound. When bromination is complete, potassium iodide is added, and the resulting solution is titrated with decinormal sodium thiosulphate solution, using starch solution as an internal indicator. A blank experiment is made at the same time in exactly the same manner as the determination proper, except that the organic compound is omitted. Whenever the excess method is applicable, it is preferable to the direct method. Day has used this procedure with good results in the quantitative determination of twenty-eight organic compounds of the aromatic series. J. S. H.

ATOMIC GROUPING IN PERMALLOY.

BY

L. W. McKEEHAN, Ph.D.

Research Physicist, Bell Telephone Laboratories, Inc.;
Member of the Institute.

Most mechanical and physical tests give us information concerning the average conditions in regions containing many thousand atoms. In the study of alloys this means that few methods of attack can distinguish between different possible arrangements of a few atoms, unless these are repeated identically throughout a relatively large volume. Even X-ray analysis can tell us little about the relation of an individual atom to its immediate neighbors, although it has been applied with some success to determine the distribution of diffracting matter within the atom. By magnetic methods, however, it now appears to be possible to gain some information concerning these very local conditions. The present communication deals with a problem in the local arrangement of atoms in an alloy and with what is believed to be a new method for the solution of such problems. The interest lies rather in the method than in the particular results arrived at, which are admittedly tentative.

In a recent paper [1] on magnetostriction I pointed out that the peculiar magnetic properties of permalloy might be due to the nearly perfect compensation, in a group containing one iron and four nickel atoms, of the magnetostrictions characteristic of the two pure metals. In the present paper I propose to describe some attempts to decide whether the group of definite structure there suggested probably exists in sufficient numbers to justify its use in the explanation of permalloy. The decision reached is that such a definite structure containing only five atoms cannot be a proper picture of the facts. Some further trials, also to be described herein, show however that a group containing but five atoms can be tolerated if the structure of the group is less closely limited and provided that there is a tendency for the arrangement of atoms in crystals of a solid solution, such as permalloy, to differ in a particular way from the purely chaotic arrangement first proposed.

[1] Jour. Frank. Inst., **202**, 737–773 (1926).

The group proposed in my previous paper may be specified as consisting of five atoms, four of nickel and one of iron, so arranged in a plane of the form {111} that the nickel atoms lie at the corners of a rectangle of edges $a\sqrt{2}/2$ and $a\sqrt{6}/2$, and the iron atom lies at its centre. The nickel atoms of such a group are all adjacent to the iron atom of the group and the whole group has the form of a Saint Andrew's cross. The five atom-centres form a point-group V^h, the twofold axes of which lie in particular crystallographic directions. One such group, for example, has for its axes the directions: [211], [$0\bar{1}1$], [$1\bar{1}1$]. Since only one of these directions is a twofold axis of the face-centred cubic space-lattice, Γ_0', and since the number of atoms in a unit of structure in this space-lattice is $4i^3$, where i is an integer, it is easy to see that the least unit of cubic symmetry which could be made up wholly of the specified groups contains 500 atoms. It is highly improbable that as many as 400 nickel atoms and 100 iron atoms can have definite positions in a crystal structure. It is much more reasonable to suppose that if the whole alloy containing 20 atomic per cent. Fe consists of such groups, they are either oriented at random, in which case the cubic symmetry of the crystals is statistical, or they are all oriented alike, in which case the symmetry is triclinic. The number of atoms in the triclinic unit of structure is $5i$, where i is an integer. In the second case the defect of cubic symmetry would probably not be detectable by X-rays, but the magnetic properties might be expected to show the resulting anisotropy. Since there are no data bearing on this point, it seems better to take the first alternative, by assuming that there is no one preferred orientation of the group, but rather that the groups are not only haphazard in order of magnetic response, but also, if possible, haphazard in orientation.

Imagine a single crystal of a solid solution, containing a large number, N, of atoms, fN of one kind, say of iron, and $(1-f)N$ of another kind, say of nickel. Assume for the time being that the atoms of two kinds are distributed at random at the points of the face-centred cubic space-lattice known to characterize iron-nickel alloys with $f < 0.7$. Let us consider how large a fraction, e, of the N atoms in the crystal can be accommodated in groups of a specified sort. If e, which may be called the

efficiency of packing, is not nearly equal to unity, the specified group can have no important part in accounting for the magnetic properties of the alloy, for one of the most striking facts about a permalloy having nearly the critical composition is that it reaches magnetic saturation under weak magnetic forces, showing that in it the magnetic behavior of nearly all the atoms is similarly conditioned. This means that if grouping is responsible for the observed behavior, practically all the atoms must be groupable. Furthermore, since e cannot be greater than the smaller of the two quantities $5f$ and $5(1-f)/4$, it is only necessary to consider values of f in the immediate neighborhood of 0.2.

Let us see if e can be calculated for any arbitrary value of f. We will first proceed in a manner familiar in dealing with probabilities. Let us choose five atoms at random in our representative crystal and write down the chance, S_1, that we have been successful in choosing the component atoms of a group. Let us again choose five atoms at random and write down the chance, S_2, that we have been successful in choosing the component atoms of a group no member of which has previously been *successfully* chosen. Continue until the chance of success falls to zero. Let $\Sigma S_n = G$, the total number of groups so found. It is apparent that $e = 5G/N$. It will be found that the indicated process is easy enough. A recursion formula can be found for S_n, and G is both finite and computable. The trouble is that G turns out in general to be equal to the smaller of the two quantities f and $(1-f)/4$ so that e always has its maximum value, which is absurd. It is easy to see, in fact, that in any particular alloy with $f < 0.2$ there is a probability greater than zero for the occurrence of an iron atom which has less than four nickel atoms adjacent to it. Such an iron atom is absolutely ungroupable in the proposed way, but the analysis says that if we try often enough it can finally be grouped. Nickel atoms with no iron neighbors are also possible in an alloy with $f > 0.2$, and are clearly ungroupable. The paradox is explained by the fact that the mathematical set-up will not look at one particular crystal but insists on considering at each step all the possible ways in which the fN iron atoms and $(1-f)N$ nickel atoms may originally have been arranged. Among all these ways there are many in which the possible groups comprise all the atoms of one kind,

and all that the analysis says is that if we try enough different crystals containing N atoms we will finally be sure to find one completely groupable in this sense.

It may be feasible to avoid this mathematical difficulty but a few trials suggested that more rapid progress would result from a different method of attack. This method, while laborious, appeared certain of success, and permitted changes in the hypotheses concerning the orientation and form of the group without involving any increase in difficulty. It may be called an experimental method to distinguish it from the purely analytical method first attempted. It consists simply in doing on paper what was imagined to be done in three dimensions in the analytical method. The method is applicable to other problems concerning solid solutions, and therefore will be described in some detail.

It is necessary to deal with so many atoms (so large a value of N) that the results shall have respectable precision. This is a severe condition, for it requires that the number of atoms on which the least accurate datum depends shall exceed p^{-2}, where p is the ratio of the probable error to the result itself. The first trial aimed at a probable error in e less than 6 per cent., which requires $fN > 264$, or, for $f = 0.2$, $N > 1320$.

Any ordinary projection of so many lattice-points would become a mere jumble, so an unusual projection had to be devised. In order to show the environment of each atom correctly a chart was made in which consecutive planes of atoms are shown in true shape while these slices of the crystal are uniformly spaced along a straight line at such an interval that there is no overlapping. (This is an oblique projection with projectors nearly parallel to the picture-plane.) The atoms adjacent to any selected atom are represented on such a chart by the spots immediately surrounding the spot representing the selected atom, and by certain additional spots in the next adjacent slices to right and to left. In what follows these spots on the chart will usually be referred to as "atoms." A stencil can always be cut which, when centred at a chosen atom and properly oriented, will show through its openings all the adjacent atoms or any selected group of them.

The lower limiting size of the imagined crystal and the manner of displaying its atoms being thus fixed, there had yet to be decided its shape, its exact size, and the type of planes to be separated as slices in making the chart. Since the crystal has

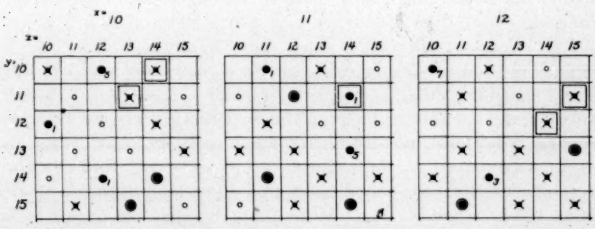
cubic symmetry a cube seemed the most convenient shape and was chosen for the preliminary trials. (Reasons for abandoning this shape in the final work will be given later.) The slices were naturally taken parallel to one pair of the faces of this cube and were therefore planes of the form {100}. The least cube which has $N > 1320$ is one of edge $7a$, where a is the space-lattice parameter or edge of the unit face-centred cube, and this cube has $N = 1688$ if, as was here assumed, the corners of the large cube are also points of the space-lattice. The rectangular coördinates of the atom-centres, referred to one corner of the cube as an origin and to the three of its edges which there intersect as axes are then 0, 0, 0; 0, $a/2$, $a/2$; $a/2$, 0, $a/2$; $a/2$, $a/2$, 0 and all other sets derivable from these by adding la, ma, na to these, l, m, and n being positive integers (including zero) limited by the condition that no coördinate shall exceed $7a$. In order, however, to be able to enlarge the hypothetical crystal by symmetrical additions without introducing negative coördinates the origin was moved to the point $(-5a, -5a, -5a)$, and in order to avoid fractions the coördinates were expressed in terms of $a/2$ rather than in terms of a. With these changes the atoms to be considered are all those from $x = 10$, $y = 10$, $z = 10$ to $x = 24$, $y = 24$, $z = 24$ (both inclusive), for which $x + y + z$ is even.

A chart showing the relations between these 1688 atoms was then constructed on squared paper in the manner already described. The fifteen slices are squares of side $7a$, each containing atoms having a common value of x and these atoms are arranged in each slice like the white (or the black) squares of a checkerboard. If x is even there are 113 atoms in the slice ($113 = 8^2 + 7^2$), if x is odd there are 112 atoms ($112 = 8 \times 7 + 8 \times 7$). The chart is so long and narrow ($64'' \times 4''$) that it was found convenient to mount it on a light pine board sliding right and left in guides mounted on an ordinary desk. With this arrangement the user does not have to move himself in order to make entries anywhere upon the chart.

The next step was to obtain a random selection of any desired number of atoms. The selected atoms can then represent, for example, the iron atoms of a nickel-iron alloy having the chaotic distribution first assumed. In order to accomplish this the set of three coördinates corresponding to each of the 1688 atoms were first stamped on as many metal-rimmed paper tags $1\frac{1}{2}''$ in

diameter. A six-digit numbering machine was used, the three two-digit coördinates thus appearing on the tag without spacing between them. A little practice makes it easy in spite of this inconvenience to read the numbers properly, *e.g.*, 191722 is read "nineteen, seventeen, twenty-two." The tags, after checking for errors, were mixed in a large lottery wheel, previously used by Dr. T. C. Fry of these laboratories in certain machine-switching problems, and were drawn, one at a time, from the rotating wheel. A list (List A) of the numbers in the order drawn was

FIG. 1.



made as the drawing proceeded.[2] Besides x, y and z, this list contains Q, the number of adjacent atoms outside the chart.

The first 338 entries ($1688/5 = 337.6$) were now assumed to be the coördinates of iron atoms in an alloy with $f = 0.2$ and the corresponding atoms on the chart were marked with a red dot. (Any other set of 338 entries not chosen with respect to coördinate values could have been used just as well.) In order to conserve the chart for later experiments the dots were not made on the chart itself but on a strip of tracing cloth tacked over it. Fig. 1 shows the upper left-hand corners of the first three slices brought close together for illustrative purposes and with large black spots instead of red dots to distinguish iron atoms. The other markings in Fig. 1 are explained below.

The search for groups in this representative alloy was conducted as follows: Twelve stencils were cut, each of which when placed on the chart with its centre at a chosen atom and with its

[2] In order to save space only a few lines of List A, and of other lists to be referred to later, are printed herewith. Photostat copies of lists A and D, which may be of value in connection with other problems, can be furnished to those interested.

long edges parallel to those of the chart showed through its openings four of the twelve adjacent atoms, the four shown being in each case members of a possible group of the specified shape. The iron atoms were considered one by one in the order in which their tags had been drawn in the lottery. (Any other random order would have served as well.) In the first search it was assumed that no orientation of the groups was preferred above another. In order to make this assumption effective the twelve stencils were shuffled and cut before dealing with each iron atom, and were used in succession until one was found which exposed unmarked atoms through all its four openings. The four nickel neighbors thus fixed upon for grouping with the central iron atom were then marked—through the stencil—with black crosses and the number of stencils that had been tried was recorded beside the red dot at the centre. If all the twelve stencils were tried without success the iron atom was marked by encircling the red dot with black. Fig. 1 has been marked in this manner to show the state of the pictured portion of the chart at the end of the process, and in one case—for the iron atom at 11 11 14—the openings in the successful stencil have been indicated by squares drawn around the proper atoms.

As the search progressed the difficulty of finding groups rapidly increased, the black crosses accumulating on the chart until they blocked practically every attempt. The state of the

TABLE I.

$N = 1688$.

Iron atoms: Chosen at random; first 1/5 from List A.
Group: 4 Ni forming a rectangle in a $\{111\}$ plane about 1 Fe.
Orientation of group: Chosen at random.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	119	100	219
4	71	25	96
7	20	1	21
9	2	0	2
Total.....	212	126	338

Efficiency of packing groups, corrected for boundary effect,

$$e = \frac{1098 - 5 \times (100 \pm 10.0)}{1098} = 1 - \frac{100 \pm 10.0}{219.6} = 0.546 \pm 0.046.$$

chart when all the iron atoms had been dealt with is summarized in Table I, which also shows how e was computed from these data.

The precision of the result for the efficiency of packing groups was adversely affected by a fact which had not been sufficiently

TABLE I.

$N = 1688$. Supplement No. 1.

Ease of Placing Groups.

Number of Stencils Tried.		
Successfully.....	1	72
	2	44
	3	21
	4	18
	5	10
	6	11
	7	7
	8	6
	9	6
	10	4
	11	7
	12	6
Unsuccessfully.....	12	126
Total.....		338

TABLE I.

$N = 1688$. Supplement No. 2.

Orientation of Groups with Respect to [211] Direction.

Number of Groups.	Inclined at
(212 × 1/12)	00° — 00′
(212 × 2/12)	33° — 33′
(212 × 2/12)	48° — 11′
(212 × 2/12)	60° — 00′
(212 × 1/12)	70° — 32′
(212 × 4/12)	80° — 24′
212* (Total)	60° — 19′ (Mean)

* Assumed to have random orientation.

considered in choosing the value of N. Too many of the 1688 atoms are peculiar in having less than twelve neighboring atoms included within the hypothetical crystal. There are in fact 8 corner atoms, 72 edge atoms and 510 surface atoms. All these are more likely to be found groupable by the method here used than are the 1098 interior atoms, because when the chosen stencils are centred at one of these boundary atoms one or more of

their four openings always fall outside the chart and if they do the chance of blocking the group is of course less than it would be if the crystal had been unlimited. There are various ways of meeting this difficulty. One way which does not involve starting again from the beginning, but which is otherwise without much to recommend it, is to correct the data on the assumption that the points lying off the chart are as likely to block grouping as those lying on it. A corner atom ($Q=9$), then, which has 3 charted neighbors and 9 uncharted would be marked as ungroupable 4 ($=12/3$) times as often as the uncorrected method indicates, an edge atom ($Q=7$), with 5 charted and 7 uncharted, 2.4 ($=12/5$) times as often, a surface atom ($Q=4$), with 8 charted, and 4 uncharted, 1.5 ($=12/8$) times as often. The proper time to throw out the excess groups is, of course, during the search. Otherwise the nickel atoms of the excess groups will hinder groups being formed around iron atoms appearing later in the list. The difficulty then arises that until the search is well advanced it is impossible to say how often, on the average, boundary atoms of the three sorts *appear* to be nongroupable. It turns out, in fact, that the proper boundary correction cannot be made unless the whole problem can be solved analytically. In Table I and hereafter the uncertainty of correction is admitted by confining attention to interior atoms, with consequently lowered precision.

It might be argued that the surface atoms in a crystal are, by reason of their location, never groupable. This would introduce an effect of grain-size upon magnetic properties, but the assumption seemed misleading in the present analysis because the volume of the hypothetical crystal here dealt with (about 1.5×10^{-20} cm.^{3}) is so much less than the size of crystals in annealed permalloy, the properties of which were in question. It seems much better to regard the boundary of the hypothetical crystal as no real grain boundary but merely as an imaginary surface enclosing part of a much larger crystal.

The applied magnetic field may be thought of as establishing a preferred direction in the crystal, and a natural modification of the first experiment was to try the twelve stencils not in a random order, but in the order of increasing angle between the axes of the corresponding groups and a specified line in the crystal. (The axes meant are [211] lines parallel to the longer sides of

the rectangle of nickel atoms.) This corresponds to assuming that groups with axes parallel to a given line are much more probable than others. For convenience the given line was taken parallel to one of the possible directions of an axis. The twelve possible groups then fall into six classes as follows:

Class.	No. of Groups.	Angle between Axes and Reference Line.
1	1	$\cos^{-1}(1) = 00° - 00'$
2	2	$\cos^{-1}(5/6) = 33° - 33'$
3	2	$\cos^{-1}(4/6) = 48° - 11'$
4	2	$\cos^{-1}(3/6) = 60° - 00'$
5	1	$\cos^{-1}(2/6) = 70° - 32'$
6	4	$\cos^{-1}(1/6) = 80° - 24'$

The same set of 338 iron atoms was marked on a fresh strip of tracing cloth and tested for groups in the same random order as before, always taking the stencils in this order (the order in each class being arbitrarily fixed). The results are given in Table II.

TABLE II.

$N = 1688$.

Iron atoms: Chosen at random; first 1/5 from List A.
Group: 4 Ni forming a rectangle in a {111} plane about 1 Fe.
Orientation of group: With long sides of rectangle as nearly as possible parallel to [211] direction.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	112	107	219
4	71	25	96
7	20	1	21
9	2	0	2
Total.....	205	133	338

Efficiency of packing groups, corrected for boundary effects,

$$e = \frac{1098 - 5 \times (107 \pm 10.3)}{1098} = 1 - \frac{107 \pm 10.3}{219.6} = 0.513 \pm 0.047.$$

In spite of a considerable degree of preferred orientation there is no significant difference in e between this case and the former one.

The natural conclusion from these two experiments was that something was wrong with the hypotheses that had been made. The hypothesis most open to doubt is the one which states that the distribution of the two sorts of atom in the solid solution is wholly haphazard. The very existence of solid solubility may

be taken to mean that the forces between unlike atoms are greater than those between like atoms. If this is true it is reasonable to suppose that the iron atoms, for example, have a tendency to separate from each other as much as may be possible instead of being arranged quite at random. The next effort was directed to

TABLE II.

$N = 1688$. Supplement No. 1.

Ease of Placing Groups.

Number of Stencils Tried.		
Successfully	1	109
	2	17
	3	25
	4	4
	5	14
	6	8
	7	5
	8	7
	9	5
	10	4
	11	5
	12	2
Unsuccessfully	12	133
Total		338

TABLE II.

$N = 1688$. Supplement No. 2.

Orientation of Groups with Respect to [211] Direction.

Number of Groups.	Inclined at
109	00° — 00′
42	33° — 33′
18	48° — 11′
13	60° — 00′
7	70° — 32′
16	80° — 24′
205 (Total)	23° — 36′ (Mean)

constructing a hypothetical alloy in which this tendency would be allowed for. It involved a new lottery.

The drawing in the second lottery was conducted in the following way: The 1688 tags were again mixed in the wheel and drawn one at a time as before. This time, however, a chart was marked as fast as the drawing proceeded. A stencil with thirteen openings was applied to this chart after each drawing in order to see whether the atom drawn was adjacent to one or

more of the atoms already marked as iron. If all twelve of the adjacent points were still blank, the coördinates were recorded and the atom was marked as iron (in red). If any of the adjacent atoms were already marked the number so marked was added to the face of the tag (in pencil) and the tag was returned to the wheel. If this tag was drawn a second time the adjacent atoms were again surveyed and the disposition of the tag depended upon the number recorded at its first drawing and upon the number of adjacent atoms now found to be marked. In case the digit 1 had been placed on the tag, and no additional adjacent points had been marked as iron during the interval between its two drawings, the coördinates were recorded and the atom marked on the chart as iron at the second drawing. In case the digit 2 appeared on the tag, and no additional adjacent points had been marked during the interval, a check-mark was placed after the 2 and the tag was returned to the wheel to await a possible third drawing when, if the situation was still unchanged, the drawing was accepted. For an atom with three or more marked neighbors at its first appearance a total of four drawings was required before the tag was finally kept out and recorded as an iron atom. If any inspection disclosed an increase in the number of marked neighbors since the last drawing, the earlier number was crossed off the tag, the new number put on, and the tag was treated thereafter as if it had had the new number placed upon it when first drawn.

This rather complicated procedure was found to be very time-consuming, and no attempt was made to draw all the tags in the wheel according to these rules, which, of course, permit finally accepting all of them. A total of 388 successful drawings (List B) was made, this being more than enough to furnish a list of the same length as that used in the first two experiments. The reason for drawing more than 338 tags was as follows: List B, unlike List A, is distorted by the superior likelihood, already alluded to, of choosing boundary atoms when the basis of choice is the number of unmarked atoms adjacent to the atom considered. In order to make comparison with the first two experiments as free as possible from the effect of this difference, List B was cut down to 338 (List C) having the same distribution of interior, surface, edge and corner atoms as the original list. The new drawing was carried just far enough, in fact, to furnish

more than enough of each classification and the atoms in each class were then brought down to the desired number by crossing out 1 of the 3 corner atoms, 3 of the 25 edge atoms, 33 of the 128 surface atoms and 13 of the 232 interior atoms. In doing this care was taken to cross out atoms of each class in a

LIST A.

x	y	z	Q
13	10	17	4
12	10	10	7
11	11	14	
19	10	23	4
14	14	10	4
18	20	14	
22	13	13	
14	20	12	
19	24	17	4
21	13	16	

LISTS B AND C.

x	y	z	Q
20	11	19	
11	24	13	4
24	10	16	7
21	22	15	
22	19	15	
17	11	14	
15	12	21	
24	19	15	4
23	18	19	
18	21	13	

LISTS D, E, F, G AND H.

x	y	z	Q
15	12	13	
15	16	27	
26	13	13	
17	20	27	
10	09	17	
26	14	18	
19	10	19	
19	20	13	
09	18	25	3
12	17	21	

LIST H'.

x	y	z
06	14	18
06	16	12
06	17	17
06	18	12
06	18	20
07	11	14
07	12	15
07	12	19
07	14	11
07	14	13

LIST H".

Index	x	y	z
622	21	16	07
533	17	09	24
515	09	17	10
461	06	17	17
414	20	14	08
363	27	18	15
	13	10	23
352	08	18	22
351	17	14	17
	19	10	09

non-selective manner by a sort of "counting out" familiar in children's games. It will be noticed that, by an oversight, the final distribution differs from that which was being matched by having one less surface atom and one more edge atom. This mistake was not discovered until List C had been used and was not regarded as sufficiently important to justify a repetition of any part of the work.

List C was next used in the third experiment, which was otherwise precisely like the first, *i.e.*, the groups of five atoms were not looked for in any determinate order with respect to a particular direction in the crystal. The results are shown in

Table III. The value of e has been raised but is still too low to suggest that the hypotheses on which this experiment depends were sound.

A more drastic step was taken in the fourth experiment,

TABLE III.

$N = 1688$.

Iron atoms: List C.
Group: 4 Ni forming a rectangle in a $\{111\}$ plane about 1 Fe.
Orientation of group: Chosen at random.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	135	84	219
4	80	15	95
7	21	1	22
9	2	0	2
Total.....	238	100	338

Efficiency of packing groups, corrected for boundary effect,

$$e = \frac{1098 - 5 \times (84 \pm 9.2)}{1098} = 1 - \frac{84 \pm 9.2}{219.6} = 0.617 \pm 0.042.$$

which also made use of List C. The special structure of the group was abandoned and it was now postulated only that each

TABLE III.

$N = 1688$. Supplement.

Ease of Placing Groups.

Number of Stencils Tried.		
Successfully.....	1	92
	2	33
	3	31
	4	17
	5	16
	6	8
	7	11
	8	5
	9	7
	10	6
	11	6
	12	6
Unsuccessfully.....	12	100
Total.....		338

groupable iron atom had four nickel atoms adjacent to it and not otherwise grouped. In order to conduct this experiment the

stencil which showed all twelve of the adjacent atoms was used, and four of these atoms were, if possible, marked as nickel, the central (iron) atom being also given an additional mark (besides its red dot) to indicate successful grouping. If no grouping was found to be possible, none of the adjacent nickel atoms was marked, and the central iron atom was marked as ungroupable. In order to avoid systematic choice of the nickel atoms when more than four of them were available for grouping, twelve tags numbered to correspond with an arbitrary numbering of the eccentric openings of the stencil were shuffled before each trial and the adjacent atoms were taken in the

TABLE IV.

$N = 1688$.

Iron atoms: List C.
Group: 4 Ni adjacent to 1 Fe.
Orientation of group: Meaningless.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	176	43	219
4	95	0	95
7	22	0	22
9	2	0	2
Total.....	295	43	338

Efficiency of packing groups, corrected for boundary effect,

$$e = \frac{1098 - 5 \times (43 \pm 6.6)}{1098} = 1 - \frac{43 \pm 6.6}{219.6} = 0.804 \pm 0.030.$$

random order so fixed until four had been marked as nickel. According to these rules of selection all corner, edge and surface atoms must be marked as groupable, since they all have at least four neighbors off the chart. There is in this experiment, therefore, even more certainly than in the earlier experiments, no information to be derived from statistics concerning boundary atoms and at the end only the interior atoms ought to be counted. Table IV shows the results of this experiment. A substantial increase in e has resulted from the greater flexibility now permitted the groups, but the value is still too low to be convincing.

The probable errors in the results so far obtained were larger than desirable, partly, of course, because boundary atoms had been found to be less informative than had been hoped.

To improve the precision the only ways open are (1) to make repeated tests or (2) to increase the number of atoms in the hypothetical crystal. The latter course was preferred because it allowed reducing the relative importance of boundary atoms. A larger cube would have furnished some improvement because the ratio of boundary atoms to total atoms decreases as the edge of the cube increases. There is still more advantage to be gained by changing the hypothetical crystal from a cube to a sphere,

TABLE V.

$N = 1688$, cube, *vs.* $N = 3716$, sphere.

Number of Neighbors Not on Chart. (Q)	Cube.	Sphere.
0	1098	2652
1		144
2		144
3		240
4	510	144
5		240
6		144
7	72	
9	8	8
Total	1688	3716
Mean value of Q	1.55	1.04

because, for the same volume (and number of atoms, if great enough) the sphere has only $\pi/6$ (= 0.52) as much surface as the cube. In order to use all the tags already marked, the sphere chosen was that which circumscribed the cube first chosen, and its radius was therefore $7\sqrt{3}a/2$. This sphere has on or in it 3716 atoms as compared with 1688 on or in the cube of edge $7a$. Of these atoms 1064 are boundary atoms in the sense that they lack some of the 12 neighbors possessed by all interior atoms (*i.e.*, they have $Q > 0$). This cannot be compared directly with the 590 boundary atoms of the cube because the degree of exposure differs for the two sets, as Table V shows, the difference being favorable to the sphere.

The second chart was constructed so as to be about of the same size as the first. This made it as easy to handle, but required considerably more nicety in construction, since the area available for each spot on the chart had to be reduced from

0.125 in.^{2} to 0.02 in.^{2}. The number of slices has increased from 15 to 25 and the number of atoms per slice, either 112 or 113 in the first chart, now varies between 4 and 233. Table V Supplement gives the distribution of irregularly environed

TABLE V.

$N = 1688$, cube, *vs.* $N = 3716$, sphere. Supplement.

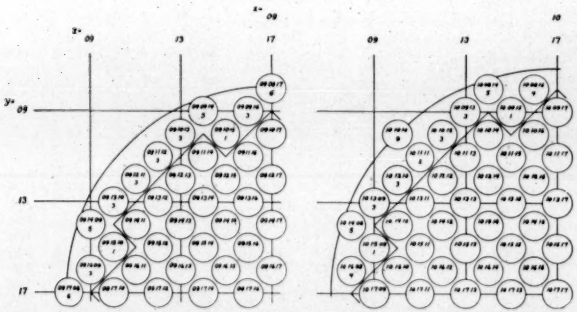
Distribution of Atoms on Charts.

Number of Neighbors Not on Charts. (Q)	0	1	2	3	4	5	6	7	9	
Cube:										
x = 10, 24					85			24	4	113
= 11, 13, 15, 17	84				28					112
19, 21, 23										
= 12, 14, 16, 18	85				24			4		113
20, 22										
Sphere:										
x = 5, 29							4			4
6, 28	1		4	4	16	12	8			45
7, 27	32	4	16			16	8			76
8, 26	57	12		12	8	8	4			101
9, 25	80	8		24		8	4			124
10, 24	101	8	4	16	8	8			4	149
11, 23	120	12	8	16		8	8			172
12, 22	145	4	8	20		8	8			193
13, 21	164		8	16	4	16				208
14, 20	177		8		8	20	8			221
15, 19	172	16	8	4	8	8				216
16, 18	185		8	4	16	8	12			233
17	184	16		8	8		16			232

atoms on the chart. A small red digit placed on the chart itself in the circle now representing each such atom gives the value of Q, so that the entry of points on a tracing, as before, can be guided if desired in accordance with the degree of exposure of these surface atoms. The form of stencils and their method of use is, of course, the same as before, the centres of adjacent slices being a fixed distance apart over the whole length of the chart, although the space occupied by the slices varies so widely. Fig. 2 shows the upper left-hand quadrants of two adjacent slices. A line is drawn separating boundary atoms from interior atoms, and a large circle represents the intersection of the plane of the slice with the circumscribing sphere. (In the actual chart the circles representing atoms are not large enough for the entry of coördinates.)

The third lottery was precisely like the first, all 3716 atoms being recorded in the order drawn. List D so obtained—or rather a photostatic copy of the list itself—was now used in an experiment which went one step farther than the last experiment of the first series. The assumption governing the choice of iron atoms from List D was simply that no two should be adjacent. List C, obtained by special rules for acceptance or rejection of

FIG. 2.



chance-drawn atoms, had actually permitted a good many cases of adjacent iron atoms and even as many as four iron atoms all adjacent to a fifth.

The procedure was as follows: The atoms were considered in the order given by List D. A stencil with thirteen openings was centred at each atom in turn. If all the twelve eccentric openings had blanks under them the central atom was marked as iron, if not it was marked as nickel. This was repeated until all the atoms had been marked one way or the other. This, incidentally, gave List D a thorough checking. Mistakes, which are inevitable at an economical speed of working, result mostly from misplacing the stencil and are later disclosed by finding a central atom already marked. They are corrected not by repeating the search for the intervening atoms, but by transposing the exchanged pair on the original list. The randomness is not, of course, affected by this transposition. The iron atoms, in the

order in which they were thus found, form List E. Table VI summarizes the results. So few of the atoms turn out to be iron on these assumptions that the maximum value of e is only 0.76, a value certainly too low to be right. A complete ban on adjacency of iron atoms thus proved too severe. There is therefore no point in testing List E for groupability.

The natural thing to try next was to see whether permitting a very small group of iron atoms to exist in an otherwise random

TABLE VI.

$N = 3716$.

Iron atoms: No two adjacent; List E.
Group: 4 Ni adjacent to 1 Fe.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	*	*	406
1	*	*	26
2	*	*	28
3	*	*	44
4	*	*	34
5	*	*	53
6	*	*	40
9	*	*	5
Total.....			636

*Experiment not made because maximum efficiency of packing groups, corrected for boundary effect,

$$e_{max.} = \frac{5 \times (406 \pm 20.3)}{2652} = \frac{406 \pm 20.3}{530.4} = 0.765 \pm 0.039.$$

distribution would arrive at a composition more closely approximating that known to be critical, and if it would then be possible to accommodate most of the iron atoms in groups of the sort already found most suitable for space-filling, *i.e.*, groups without other limitation than that every one of the four nickel atoms must be adjacent to the iron atom.

The largest group of adjacent iron atoms which ought not to introduce distortions of the angles of the space-lattice contains only two atoms, for three atoms can form a triangle, and if they do, the triangle may tend to be like the not quite equilateral triangles formed by adjacent atoms in body-centred iron rather than like the equilateral triangles formed by adjacent atoms in a perfectly built face-centred crystal. (The angles of the former

triangle are $70° - 32'$, $54° - 44'$, $54° - 44'$.) It was therefore assumed in the next search for iron atoms that two such atoms might be adjacent but that more than two would separate into pairs (or pairs and singles) completely isolated by intervening nickel atoms.

List D was used again in the appropriate way. In this case it was necessary to distinguish between iron atoms already selected but not yet adjacent to others and iron atoms forming parts of completed pairs. In order to do this two marks were used for iron atoms in constructing the new tracing of the chart. If no adjacent atom was marked as iron the atom under consideration was marked by a small dot. If an adjacent atom was marked by a dot (not more than one could be so marked, barring mistakes) this dot was surrounded by a small circle and the atom under consideration was also marked with an encircled dot. If any number of encircled dots were found among the adjacent atoms the atom under consideration was marked as nickel, *i.e.*, by a cross. List F contains the iron atoms thus selected from List D. Table VII shows how nearly the number of atoms so

TABLE VII.

$N = 3716$.

Iron atoms: Not more than two adjacent; List F.
Group: 4 Ni adjacent to 1 Fe.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	425	83	508
1	37	2	39
2	38	2	40
3	52	5	57
4	28	10	38
5	48	15	63
6	44	8	52
9	2	3	5
Total.....	674	128	802

Maximum efficiency of packing groups, corrected for boundary effect,

$$e_{max.} = \frac{5 \times (508 \pm 225)}{2652} = \frac{508 \pm 22.5}{530.4} = 0.958 \pm 0.042.$$

Observed efficiency of packing groups, partially corrected for boundary effect,

$$e = \frac{5 \times (508 \pm 22.5) - 5 \times (83 \pm 9.1)}{2652}$$

$$= (0.958 \pm 0.042) - (0.156 \pm 0.017)$$

$$= 0.802 \pm 0.045.$$

found agrees with the number to be accounted for in the alloy of critical composition, the value $e = 1$ lying just within the range defined by the probable error in $e_{max.}$. The next thing in order was to see whether in the alloy thus constructed, nearly all the iron atoms could actually be grouped.

The search for groups was first conducted just as in the fourth experiment. The degree of success in placing groups to include the atoms of List F can be judged from the results given in Table VII, and is hardly as good as hoped for though better than that of the best previous experiment. One reason for this is that List F, like List B, contains too many boundary

TABLE VIII.

$N = 3716$.

Iron atoms: Not more than two adjacent: List G.
Group: 4 Ni adjacent to 1 Fe.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	446	62	508
1	34	2	36
2	33	0	33
3	43	0	43
4	25	0	25
5	37	0	37
6	26	0	26
9	1	0	1
Total.....	645	64	709

Observed efficiency of packing groups, corrected for boundary effect,

$$e' = \frac{5 \times (508 \pm 22.5) - 5 \times (62 \pm 7.9)}{2652}$$

$$= (0.958 \pm 0.042) - (0.127 \pm 0.015) = 0.831 \pm 0.045.$$

atoms which interfere with the grouping of interior atoms either directly or by using up nickel atoms otherwise available. In order to avoid this source of error List F was normalized, in what must be admitted to be an arbitrary manner, by cutting off from each series of iron atoms in List F having the same value of Q, the last $Q/12$ of the series, as nearly as integral values permitted. The justification for this procedure is that by it the proportion of iron atoms among the 1064 boundary atoms becomes 0.189 ± 0.013, *i.e.*, equal within limits of error to the corresponding value 0.192 ± 0.008 for the 2652 interior atoms.

The resulting distribution of atoms (List G), therefore, is substantially independent of boundary errors.

A repetition of the last experiment with List G in place of List F gave as expected, an appreciably higher efficiency of packing, as is shown in Table VIII. During the progress of this search it also became clearly apparent that better packing efficiency would result if the nickel atoms with the fewest iron neighbors were used first in the formation of groups, leaving the nickel atoms with most iron neighbors available for later

TABLE IX.

$N = 3716$.

Iron atoms: Not more than two adjacent; List H''.
Group: 4 Ni adjacent to 1 Pe.

Number of Neighbors Not on Chart. (Q)	Grouped. (G)	Not Grouped. ($fN - G$)	Total. (fN)
0	492	16	508
1	36	0	36
2	33	0	33
3	43	0	43
4	25	0	25
5	37	0	37
6	26	0	26
9	1	0	1
Total.....	693	16	709

Observed efficiency of packing groups, corrected for boundary effect,

$$e = \frac{5 \times (508 \pm 22.5) - 5\,(16 \pm 4.0)}{2652}$$

$$= (0.958 \pm 0.042) - (0.030 \pm 0.008) = 0.928 \pm 0.043.$$

use. It also seemed worth while to improve on List G, which had by reason of its method of derivation from List F no high values of Q near its lower end. This suggested the final experiment.

List F was cut down anew so as to have the same extent as List G, but the rejected atoms were now spread uniformly throughout the list instead of being taken from the lower end alone. This supplied a new list (List H). These atoms were marked as iron on a new tracing and the 3007 remaining (nickel) atoms were then surveyed with the usual thirteen-opening stencil, the number of iron neighbors for each being entered in pencil on the chart itself. The nickel atoms were found to fall into six

classes according to the number of iron neighbors, from 0 to 5, inclusive. The 709 iron atoms of List H were next surveyed (without marking them), and an auxiliary list (List H′) was made in an order of ascending x, y and z. This list contained besides x, y and z, the value of Q, the number of adjacent nickel atoms of each class, P_1, P_2, P_3, P_4, P_5 (P_i is the number having i iron neighbors), and the number of adjacent iron atoms, $P_f(P_f \geqslant 1)$. A useful check on List H′ is found in the condition $Q + \Sigma P = 12$. A third auxiliary list (List H'') of the same 709 iron atoms was then made in an order dependent upon the classification of adjacent atoms and designed to put interior iron atoms which furnish the sole or principal hope for the grouping of many nickel atoms at the head of the list. An index number for determining this order was made up of three digits. The first was $(P_1 - Q)$, the second was P_2 and the third was P_3. List H″ was arranged in descending order of index numbers, atoms with the same index number being placed in a random order. List H″ was used to fix the order of search for groups in the now customary manner. A slight additional improvement in packing efficiency was sought for, however, by using first in each attempt at grouping those adjacent nickel atoms with the least number of iron neighbors (as entered thereon in pencil), care being taken in the usual way to make the selection of equally available nickel atoms quite at random. Table VIII summarizes the results and yields a value of e which is high enough to make further special assumptions, and *particularly* the assumption of larger groups, unnecessary. This value of e is, indeed, not quite the highest value of e consistent with the new rules of selection, for after cutting down List F it is clear that a few additional iron atoms might have been placed in the interior without violating the rules and some at least of these would have proved groupable.

It is concluded on the basis of this quasi-experimental analysis that groups containing only five atoms—four of nickel all adjacent to one of iron but not otherwise restricted—suffice to explain the magnetic peculiarities of permalloy. Such groups are, in the mathematical sense, sufficient but not necessary. It remains to be explained in more physical ways how such a group can change its magnetic state with so little hysteresis.

There are two other questions in the investigation of which the new graphical method for studying alloys may be found useful. One is in the study of so-called resistance limits, *i.e.*, compositions dividing easily dissolved alloys from those which resist solvents without appreciable loss in weight.[3] The other is in the study of resistivity in moderately dilute solid solutions. In both cases the peculiarities observed may be traceable to regularities in structure which are of too fine-grained a sort to give X-ray evidence of their existence and such regularities may have to be inferred from the composition in ways analogous to that here followed in the treatment of permalloy.

[3] Masing, G., *Wiss. Veröffentl. a. d. Siemens-Konzern*, **5**, 156–169 (1926), has made some progress in this problem by a two-dimensional experiment analogous in some respects to that here described.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

LENGTH AND ANGLE MEASUREMENT LABORATORY AND EQUIPMENT.

A NEW room specially constructed for use as a high-precision length measurement laboratory has recently been completed at the bureau. The installation of equipment is now in progress. This room was excavated below the physical laboratory building, and owing to its location and construction the temperature changes are small. In addition, thermostatic regulation of the temperature is provided by electric heating. Space, as well as electrical and plumbing connections, have been provided for a later installation of equipment for cooling the room if found desirable. Massive piers have been constructed on which the equipment is to be mounted, these piers being separated from the floor, so that neither vibration nor distortion of the piers nor apparatus will be caused by observers walking or standing in the room. Detailed plans were worked out for the location of equipment, electrical wiring, and plumbing before the work of construction was begun. In consequence this laboratory is especially well arranged for precise work, and will be provided with every facility which experience has shown to be useful. There is no excess of space, but even with all of the equipment in place it is believed that there will not be an over-crowded condition.

A circular dividing engine with a table one metre in diameter and having an accuracy claimed by the maker to be within one-half of a second of arc is one item of the new equipment for this room. This will be used for graduating precision theodolites and other geodetic and physical instruments. It is expected that a considerable amount of graduating for the U. S. Coast and Geodetic Survey will be done on this machine. Accompanying this is a circle testing machine for calibrating the errors of graduation of divided circles.

The bureau's precision one-metre transverse length comparator has already been moved from its former location to this room. Plans are now under way to make some alterations in this comparator so that it will be adequate for the requirements of modern

* Communicated by the Director.

precision measurement. A new comparator having a longitudinal motion has been purchased and its installation is expected early this fall. This new comparator is especially designed for calibrating the sub-intervals of a graduated line standard, whereas the transverse comparator is especially designed for comparisons of the total lengths of two standards.

All the work to be done in this laboratory is of a fundamental nature. When the equipment is all in place and in operation, and when changes now contemplated in the transverse comparator have been completed, it is believed that this new laboratory will be one of the best, and probably the best, of its kind in the world.

THERMAL EXPANSION OF BERYLLIUM AND ALUMINUM-BERYLLIUM ALLOYS.

DATA on the linear thermal expansion of beryllium were reported in *Technical News Bulletin No. 118,* February, 1927. The investigation on the thermal expansion of this metal and aluminum-beryllium alloys (4 to 33 per cent. beryllium) was undertaken because of the interest shown in aluminum-beryllium alloys in connection with automotive engine pistons; there being no information available on this subject. Expansion determinations were made over various temperature ranges between −120 and +700° C. on a sample of beryllium (98.9 per cent.), and between room temperature and 500° C. on the aluminum-beryllium alloys.

Beryllium, a metal about 30 per cent. lighter than aluminum, has received until recently very little attention. This interesting metal expands considerably less than aluminum and approximately the same as iron or ordinary steel.

Aluminum-beryllium alloys also expand less than aluminum. For example, an aluminum-beryllium alloy containing 30 per cent. beryllium has coefficients of expansion approximately 20 per cent. less than those of aluminum. The relations between the coefficients of expansion and the chemical composition were compared with the equilibrium diagram obtained by Oesterheld, and were found to be in agreement with the theory for this type of diagram.

A Scientific Paper which gives detailed data on beryllium and aluminum-beryllium alloys is now in press. It is believed that this paper will be valuable to persons interested in the properties of light alloys.

MEASURING THREAD ANGLE OF TAPER THREAD RING GAUGES.

The thread angle of ring gauges is usually determined from a plaster cast of the thread, and the angle of the two sides of the thread is reported with relation to a line perpendicular to the axis of the thread. Ordinarily this line should bisect the total thread angle. In determining the half-angle, reference is made to the minor diameter of the ring as shown by the cast, the minor diameter being assumed to have the nominal taper. The correctness of this assumption can be checked for a straight thread ring by ascertaining whether or not the minor diameter of the ring is the same at both ends. In the case of a taper ring, if of sufficient length, the difference in minor diameter at the two ends serves as a basis for the angle measurements. For a thin ring with a taper thread, measurement of the minor diameter is not sufficient check, and in general, is not a satisfactory method. To overcome this difficulty, a plain taper plug hardened and ground with known taper equal to the nominal taper of the minor diameter of the ring has been made. This plug has a longitudinal slot in which the cast can be made when the ring is slipped on the plug. After the cast has set, the taper plug is first removed from the ring and then the cast is removed from the ring. For measurement of thread angle in the thread projector, the cast is inserted in the slot of the taper plug gauge and the outside of the taper plug is used as the reference in determining the errors in half-angle of thread. One taper plug has been made and used and other sizes will be made as required.

ROAD TESTS OF AUTOMOBILE HEADLIGHTING.

The bureau has coöperated with the Society of Automotive Engineers and the Illuminating Engineering Society in research work on various phases of the automobile headlighting problem. Research associates assigned to the automotive power plants section have been engaged for several months in a systematic study of the types of light distribution required for satisfactory vision under usual driving conditions in the absence of opposing traffic. This work is done late at night on nearby highways, using cars provided with special test equipment which includes four headlamps mounted side by side on a bar so that they can be aimed

individually or collectively. These lamps have interchangeable lenses of various kinds and the brightness of the lights is controlled by means of rheostats.

The usual method of test is to set up a dummy, about the size and shape of a grown man, and to record the various distances at which it can be seen and identified under various conditions with various lighting distributions. As might be expected, the darker the night, the greater the visibility for a given beam intensity and pattern. Visibility is found to be practically the same for all speeds between a walk and 40 miles per hour. The effect on visibility distance of tilting the beam and of using lenses which give various vertical and horizontal spreads has been studied and the data are represented graphically by a series of three dimensional figures carved out of wood.

Attention is now being directed to a study of optimum illumination when meeting other vehicles. For use in this work, a test car belonging to the bureau has been equipped with one of the four head-lamp test sets and other special devices. The four head-lamps are mounted at the rear of this car but are controlled from the driver's seat as is a dummy which is carried on the right-hand running board. This car keeps some distance in advance of the observer's car until a suitable test location is reached. The driver then swings to the left, stops and turns on his rear headlights, to simulate a car coming from the opposite direction. He also swings the dummy out alongside of his car. The observer keeps on until he can definitely distinguish the dummy beyond and to the right of the opposing lights. For convenience in measuring visibility distance, the observer uses an Army aiming circle as a range finder.

The National Automobile Chamber of Commerce has provided funds for this series of road tests which are under the general direction of a joint steering committee on headlight research. It should be pointed out that the present program contemplates no tests of commercial headlighting equipment. The aim is to ascertain what types of light distribution are preferable from the automobile driver's point of view. What devices will best serve to realize such optimum light distribution is a practical problem which must be left to the car and lamp manufacturers.

SHIPMENT OF STANDARD CELLS TO JAPAN.

International agreement on fundamental standards is of the utmost importance. With the object of promoting standardization among nations, the bureau has always taken an active part in coöperative research in many fields.

The International Bureau of Weights and Measures has adopted a program for the intercomparison of the fundamental electrical units as maintained by the various national laboratories. One of the most important matters in such interlaboratory comparisons is the transmission of the actual standards from one laboratory to another. This is especially true of standard cells.

The Bureau of Standards recently shipped to Japan four standard cells of the unsaturated type. Two of these cells belong to the Japanese Government and the other two were made at the bureau. One had been to Japan before for comparison.

The cells were packed in a small box hung on gimbals within a larger box, which in its turn was packed in an ordinary packing case. This precaution is necessary to avoid the possible mixing of the contents of the two legs of the cell, which occurs when the cell is inverted.

STORAGE BATTERY FOR WASHINGTON MONUMENT.

The electric elevator of the Washington Monument is required to perform somewhat peculiar and exacting service. A large number of passengers must be handled on each trip and owing to the great height of the shaft and absence of natural illumination any failure of the power must be carefully guarded against.

An interesting request was received by the bureau from the Director of Public Buildings and Public Parks to determine the feasibility and required capacity of a standby storage battery installation to operate the elevator in case of interruption to the usual power supply. As a result of this investigation reports have been prepared and submitted on the current consumption of the elevator, on a storage battery to care for the elevator motor and lights, in an emergency, and on a specification for this battery.

The plan appears to be a feasible one.

ACCELERATED WEATHERING TESTS FOR PAINT AND VARNISH.

THE equipment designed by the bureau for accelerated weathering tests on paint and varnish has now been in use for seven months and is giving very encouraging results. The apparatus supplies a cycle of four exposures: Light, water, refrigeration, and ozonized air, to which all samples are subjected, the complete cycle, with time for inspection, occupying twenty-four hours. The total length of the test can be varied as seems desirable.

The material to be tested covers 3 × 6-inch panels, and the four parts of the apparatus are designed to accommodate samples of this size.

The light tank is an open cylinder of galvanized iron, 30 in. in diameter and 15 in. high. The cylinder is supported above a pan of water with an air opening between the surface of the water and the lower edge of the cylinder, so that there is an upward current of air passing over the water and up through the cylinder. Attached to the inside surface of the cylinder are 30 slotted holders for the test panels. The light, which is mounted in the centre of the cylinder, is a flaming carbon arc, the spectrum of which approaches closely that of sunlight.

The ozone equipment employs regular commercial apparatus for ozonizing the air and a glass tank in which the specimens are exposed. Water is kept in the bottom of this tank to moisten the ozonized air. As used in this work, the apparatus delivers about 660 litres of air per hour, containing 0.56 litre of ozone, or about 0.08 per cent. ozone (by volume).

In external appearance the rain tank is similar to the light tank but of smaller diameter. It is provided with holders for the test panels, and contains a revolving lawn sprinkler. Water at a temperature of 34° C. is used.

The refrigeration equipment involves no unusual features.

The regular test program is made up as follows: Exposure to ozonized air for three hours, rain for three hours, light for seventeen hours, and inspection one hour. In addition, on three days a week, the panels are subjected to refrigeration at a temperature of −23° C. (−10° F.) for one hour, one-half hour being subtracted from the periods for exposure to ozone and rain.

The order of exposure is varied on different days, and as

before mentioned, the total length of the test may be altered as required.

EXPANSION OF NEAT PORTLAND CEMENT IN STEAM.

AN investigation was made of the volume changes produced in various Portland cements when neat cement specimens were subjected to steaming and boiling tests. Data were secured on thirty-two different cements when tested by the following four methods: (*A*) The regular specification test, five hours' steaming of cement pats; (*B*) the LeChatelier tongs test, involving six hours' boiling; (*C*) bars, 1 × 1 × 6 inches, steamed five hours, and measured by a special micrometer, bearing against glass inserts in ends of bars; (*D*) identical bars and treatment as in preceding test, but measurements made microscopically by comparator, using glass capillary tubing inserts for markers. The neat cement bars were stored in a constant temperature cabinet, maintained at 70° F. prior to test and for one hour after their removal from the steam, when the final measurement was made.

No deductions are herein made as to the relative merits of these cements, as indicated by the results of these tests. However, the following brief observations are interesting:

(1) The usual specification test of the neat cement pats did not give any indications of the relative expansive properties of the cements. All of the cements were "sound."

(2) The LeChatelier tongs did not give very concordant results, nor did the results seem to agree very closely with those obtained by methods *C* and *D*.

(3) Test method *C* showed that the expansion of none of the cements was great, compared with what might be expected of those cements which would prove to be "unsound" in the specification tests of pats. However, the tests of the bars did show that the relative expansive properties of some of the thirty-two cements varied widely, being grouped as follows:

Group.	Number of Cements in Group.	Expansion Obtained. Per cent.
1	7	0.000 to 0.010
2	12	.011 to .020
3	7	.021 to .030
4	5	.031 to .040
5	1	.061

(4) In general, the results of method *C* were confirmed by

method *D*, but the latter method did not give such concordant results for individual tests as *C*, notwithstanding the more elaborate and precise nature of the comparator instrument. It is thought that slight warping of occasional specimens may have greatly disturbed the relative directions of the glass tubing inserts. Method *D* was much more difficult and consumed more time than method *C*.

(5) The foregoing is based on the tests of cement mixed to a "normal consistency." The series of tests was then repeated using a wetter mix, containing 42 per cent. of water (per cent. by weight of cement). The results obtained confirmed the observations made on the specimens of normal consistency, although some slight changes would be produced in the grouping as given above.

FINENESS OF SLAKED CHEMICAL QUICKLIME.

A DETERMINATION of the "fineness" of slaked chemical quicklimes has been undertaken. The data obtained will form the basis of specifications covering lime for use in chemical industries. Many of these industries find it advantageous to use quicklimes in order to utilize the heat of hydration. This principle is used, for example, in the liberation of ammonia from the ammoniacal liquors produced in the by-product coke industry. In those industries in which quicklime is used as a reagent, it is desirable that the disintegration of the quicklime, during the process of hydration, should be as complete as possible. A fine state of subdivision increases the rate of solubility and the speed of reaction. Coarse material not only decreases the solubility and efficiency of the lime, but also has a deleterious effect on processing machinery.

In the method which the bureau is following in its fineness determinations a 100-gram sample of quicklime is added to an excess of water. The lime-water mixture is agitated frequently during the first hour. During the next twenty-three hours the mixture is stirred six times. The stirring is carried on cautiously to prevent the mechanical disintegration of the large particles which naturally occur. Of the samples of quicklime only one was of dolomitic origin, in which case precautions were taken against drowning. The mixture was then poured through a series of standard sieves nested as follows: Nos. 30, 50, 100 and

200. The determination of the amount of material retained on the sieves, as washed through by using a moderate stream of water from a one-quarter inch rubber tube, followed substantially the practice recommended by the American Society for Testing Materials for determining the fineness of mazon's hydrated lime. The washing was continued until the water passing through the sieves was clear. In no case was it found necessary to continue the washing for over ten minutes. The sieves were placed in an electrically heated drying oven for one hour and the contents on each sieve finally weighed.

The following results give the progress of this investigation to date:

Through Sieve No.	Retained on Sieve No.	Sample No. 11	21	24	28	35
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
...	30	0.9	2.2	3.1	10.3	3.1
30	50	0.8	1.7	2.3	2.2	7.4
50	100	2.6	0.7	1.3	2.1	6.9
100	200	0.9	2.2	3.7	2.2	5.6
200*	...	94.8	93.2	89.6	83.2	77.0

*By difference.

QUALITIES OF FIRE-CLAY REFRACTORIES.

THE study of the fundamental qualities of representative fire-clay refractories and individual clays has been referred to and described in *Technical News Bulletin No. 117* (January, 1927) and *No. 121* (May, 1927). The effect of reheating at high temperatures on the thermal dilatation has now been observed. The importance of thermal dilatation as a factor controlling resistance to thermal spalling has been discussed at length in recent literature and the significance of differential thermal dilatation and fibre elongation was briefly referred to in *Technical News Bulletin No. 121*. Factors of possible significance are not only the differences in thermal dilatation of the various constituents of the refractory structure, but also the difference in thermal dilatation between one portion of a structure and an adjacent portion.

In actual service nine-inch brick are usually laid in header courses, that is, only the $2\frac{1}{2} \times 4\frac{1}{2}$-inch end is exposed directly to the heat. Since fire-clay refractories are fairly good heat insulators, the maximum temperature 2 inches from the "hot

face" may never exceed 1200° C. (2200° F.), even though the hot face is heated for prolonged periods as high as 1450° C. (2642° F.). Since clay refractories are initially fired at temperatures from 1250 to 1275° C., it is unlikely that the structure 2 inches from the hot face would be greatly affected in service. However, the data obtained show that the material at and immediately adjacent to the hot face may be changed very materially as regards thermal dilatation.

Average values for seventeen representative brands of fireclay show that reheating at 1400° C. (2552° F.) for five hours reduced the per cent. linear thermal expansion and contraction of the brick (calculations based on values obtained on brick as received) by 0.04 per cent., and that the per cent. linear expansion from room temperature to 900° C. has been changed by 0.1 per cent. Furthermore, reheating at 1500° C. for five hours changed the per cent. linear expansion, from room temperature to 200° C., an average of 0.07 per cent., and from room temperature to 900° C. it was changed 0.15 per cent. Certain brick of the siliceous type showed changes greatly exceeding these average values. The maximum changes observed were as follows: (*A*) (after reheating at 1400° C. for five hours) room temperature to 200° C., 0.09 per cent. change in linear thermal expansion; room temperature to 900° C., 0.17 per cent.; (*B*) (after reheating at 1500° C. for five hours) room temperature to 200° C., 0.16 per cent.; room temperature to 900° C., 0.30 per cent.

A preliminary report of this phase of the investigation, together with a discussion of its significance as regards thermal spalling, was published in the September, 1927, issue of *Fuels and Furnaces*.

FUNDAMENTAL STUDY OF GLAZE FIT.

AN INVESTIGATION is being conducted at the Columbus branch of the bureau to determine the effect of the various oxides on the tensile strength, modulus of elasticity, and coefficient of expansion of glazes. To date about eighty-five glazes have been melted into rods and the tensile strength and modulus of elasticity determined. The coefficient of expansion has been determined on about twenty of the glazes.

The modulus of elasticity and tensile strength are not strictly straight-line functions of the batch composition of the glazes.

This is especially true of glazes containing boron and lead. Factors, applicable to the various oxides, have been worked out for the modulus of elasticity and the tensile strength of the glazes. These factors enable one to calculate the two properties with about the same accuracy that can be obtained in the actual measurements. Some of the factors for a given oxide vary, depending on the total amount of the oxide present in the glaze.

The following observations have been made during a study of crazing:

(1) Crazing may take place either (*a*) as soon as the ware is removed from the kiln or (*b*) several months after the body is removed from the kiln. This latter type of crazing is caused by changes which may take place in the body, such as rehydration, or by changes which may take place in the glaze. Such changes take place in glass and are designated as "afterworking of the glass." In this case the change is a contraction. It is significant that sodium and potassium glasses have a considerable afterworking change, which is reduced by increasing the line and alumina. Both of these changes would tend to throw a glaze that was initially in compression, to tension, thus producing crazing.

It is fully realized that the batch composition does not represent the ultimate composition of the glaze because of the volatilization of certain constituents and the reaction of glaze and body constituents. However, given a certain glaze and body composition it is hoped that the information obtained in this study will enable one to vary the physical properties of the glaze by varying the chemical composition, so that a better fit can be obtained between body and glaze. This will be true if the effect of each oxide on the various physical properties is known.

Organic Precipitation of Metallic Copper.—The precipitation of metallic copper by organic matter is the subject of an investigation by T. S. LOVERING (*U. S. Geol. Survey Bull. 795 C*, 45–52 1927). Metallic copper occurs in thin beds of black muck in a bog near Cooke, Montana. The copper particles range in size from minute specks to lumps over one inch in diameter; these lumps are loose and spongy masses of crystals. Neighboring sulphide ores of copper oxidize to cupric sulphate which is carried to the bog in solution, and then deposited as the metal. This deposition is due to the reducing action of the waste products of metabolism of bacteria present in the muck. Thus certain swamp bacteria, such as *Bacillus coli* and *Bacillus proteins*, decompose complex proteins and polysaccharides and produce numerous compounds, including amino acids and monosaccharides. In an anaërobic environment, *i.e.*, in the absence of oxygen, a mixture of glycocoll (an amino acid) and either levulose (a hexose sugar) or xylose (a pentose sugar) reduces an aqueous solution of cupric sulphate with the precipitation of metallic copper. The reaction occurs slowly at room temperature, more rapidly at a temperature of 60° to 70° C.; the solution must be either neutral, or faintly acid, or faintly alkaline. J. S. H.

Organic Bases and Soluble Tungstates.—EDGAR F. SMITH, of the University of Pennsylvania (*Proc. Am. Phil. Soc.*, 1926, **65**, Supplement, 10–17), has used certain organic bases as precipitants for the tungstic acid present in soluble tungstates, including normal tungstates, metatungstates, and paratungstates. The tungstic acid was precipitated quantitatively from soluble tungstates of all three series by benzidine acetate, by quinine sulphate, and by salts of cinchonine and cinchonidine; difficulty was experienced in washing the precipitates produced by the cinchona alkaloids free from inorganic salts. Aniline hydrochloride precipitated only soluble paratungstates; the precipitation was incomplete. Pyridine hydrochloride and orthotoluidine hydrochloride produced precipitates with soluble salts of all three tungstic acids; but the precipitation was not quantitative. In the course of the research, determination was made of the delicacy of the test for tungsten with metallic zinc and hydrochloric acid (formation of a blue color). Reliance could not be placed on this test when less than 0.04 gram of tungsten trioxide, WO_3, was present in 50 c.c. of solution. J. S. H.

Irradiated Milk Powder.—WALTER H. EDDY (*Arch. Pediatrics*, 1927, **44**, 320–321) reports that anti-rachitic power is imparted to milk powder, derived from either whole or skim milk, by exposure of a layer of the powder 2 mm. thick to the ultra-violet rays for a period of two to five minutes. Use of 5 per cent. of the irradiated powder in the ration of rats prevented the development of rickets. The powder retained this property for six months when kept in sealed, sterile containers. J. S. H.

NOTES FROM RESEARCH LABORATORY, INCANDESCENT LAMP DEPARTMENT OF THE GENERAL ELECTRIC COMPANY.*

CRITICAL PRIMARY VELOCITIES IN THE SECONDARY ELECTRON EMISSION OF TUNGSTEN.

By Herman E. Krefft.

A BEAM of primary electrons of uniform velocity, limited by a system of diaphragms, strikes a tungsten target, the secondary emission of which is received by a collecting cylinder surrounding the target. In order to make sure that the surface of the tungsten target is as free as possible from gas layers, measurements were carried out while the target was heated up to 1480° K., the vacuum being of the order of 10^{-8} mm. of Hg. No ground joints or cemented parts were used in the design of the tube which was sealed off the pump after baking and operating for a sufficient length of time. This high vacuum was then maintained solely by charcoal immersed in liquid air. A vacuum of this high degree is of great importance for the production of the phenomena found in this investigation. A large number of measurements were taken in the range of 10 to 700 volts primary velocity with the target at room temperature, after previous heating, and at temperatures varying between 1250° and 1480° K.

The secondary emission curve of tungsten, *i.e.*, the curve giving the number n of secondary electrons produced by one primary electron, as a function of the primary velocity, thus taken with a well-degasified surface, has a number of breaks, some of which give rise to changes of slope of the secondary emission curve. There is a maximum at 15.5 volts primary velocity, a minimum at about 20 volts, downward inflections near 65, 100 and 525 volts and upward inflections near 185, 235 and 495 volts, the number n increasing between 20 and about 630 volts, where n reaches its maximum value, which, in one case, was found to be 1.40.

With the tungsten at temperatures ranging between 1250° and 1480° K., 19 breaks were found above 25 volts in the secondary emission curve. The primary velocities and corre-

* Communicated by the Director.

sponding ν/R-values for these breaks are given in the first two columns of the table. In the third column critical potentials found by Richardson and Chalklin in the soft X-radiation of tungsten are shown, and in the fourth and fifth columns the

TABLE.

Critical Primary Velocities in Secondary Emission (Volts).	ν/R-values.	Critical Potentials in Soft X-radiation (Not Corrected for Work Function of Target).	Bohr and Coster.	Nishina.
29.5	2.18	31.94		
33.0	2.44	35.4	$N_{33,\ 44}=2.5$	
38.7	2.86	40.0	$O_{21,\ 22}=2.9$	$N_{44}=2.8$ $N_{43}=2.9$
60.3	4.46			
64.8	4.79	65.9		
69.3	5.12		$O_{11}=5.2$	$O_{21,\ 22}=5.2$
74.8	5.53			$O_{11}=5.7$
109.2	8.08	103.3		
127.7	9.44	122.8		
237.5	17.56	240.3	$N_{33}=17.8$	
249.0	18.40		$N_{32}=18.7$	$N_{33}=18.4$
257.5	19.04	258.8		$N_{32}=18.8$
390	28.8	390		
415	30.7	414	$N_{22}=30.6$	
446	33.0			$N_{22}=33.0$
457	33.8			
495	36.6		$N_{21}=35.6$	
523	38.7			$N_{21}=38.0$
590	43.6		$N_{11}=43.6$	$N_{11}=44.1$

ν/R-values for the N- and O-energy levels of tungsten, as computed by Bohr and Coster and by Nishina. There is a good agreement between the breaks of the secondary emission curve and those found in the soft X-radiation. A comparison with the computed values for the N- and O-energy levels of tungsten gives good evidence that some of the breaks of the secondary emission curve are due to these levels.

The vacuum in the tube, while operated, is of such a degree

that, when the heating of the target is discontinued, the adsorption of gases by the cold tungsten takes place only very gradually, these gases being liberated from other electrodes by the discharge. With cold tungsten, shortly after heating, while it is still well degasified, a few additional breaks are observed besides those found at high temperatures. Generally, with cold tungsten in this condition the breaks are more intensive than with hot tungsten. None of these breaks are observed when the tungsten gets beyond a certain stage in the adsorption of gases. This fact explains why the numerous breaks measured in this investigation were not found by other observers.

The shape of the secondary emission curve in the range of 10 to 25 volts primary velocity, taken with cold tungsten, depends greatly on the amount of gas adsorbed. The maximum at 15.5 volts which is more intensive with cold tungsten, shortly after heating, than with hot tungsten, is probably due to a surface layer of oxygen molecules. The fact that this maximum exists at temperatures up to 1480° K. proves that the surface of tungsten cannot be considered as entirely freed from oxygen up to this temperature.

The effect of adsorption of gas is to increase n for low velocities, while for higher velocities the reverse is true. Both with cold and hot target n varies with time, as long as adsorption or liberation of gas takes place. The variation of n with time may be thus used to follow up adsorption or liberation of gas by a metallic surface in a high vacuum.

Airplane to be Tried Against Sugar-cane Insect. (U. S. Department of Agriculture, Press Service.)—The expenditure of $50,000 to conduct a large-scale experiment on the effectiveness of airplane dusting to control the sugar-cane moth borer has been authorized by the Secretary of Agriculture. Approximately 5000 acres of sugar cane in the heart of the sugar-producing area of Louisiana will be dusted with sodium fluosilicate to determine the efficiency of such treatment in controlling the borer. The experiment is being conducted at the request of the American Sugar-cane League, planters, manufacturers of cane products, bankers, and others interested in the sugar-cane industry. At the present time the borer is found throughout the territory and its damage to the cane crop runs from 15 to 30 per cent. of the total crop annually.

The most effective way to control this borer, says the Department of Agriculture, is to submerge seed cane in water for seventy-two hours before planting, which is certain death to the borer. It is hoped by the planters and others interested in the sugar-cane industry that the experiment in airplane dusting may prove to be equally effective and more economical. It is planned to administer the first dusting beginning August 1. Following the first dusting, two further applications will be made a month apart, around September 1 and October 1.

The experiment will be conducted under the general direction of Dr. A. F. Woods, Director of Scientific Work, Department of Agriculture. The Department Bureau of Entomology will have direct supervision of the work, with Dr. W. H. Larrimer in administrative charge in Washington. T. E. Holloway, Associate Entomologist in charge of the Department field station at New Orleans, La., will be in charge of the field operations. The 5000 acres will be selected from cane areas in which have been planted disease-resistant varieties developed by the Office of Sugar-cane Investigations of the Bureau of Plant Industry. The preservation of these valuable varieties for seed purposes is of vital importance to the industry. Dr. E. W. Brandes and Dr. R. D. Rands, of the Bureau of Plant Industry, will be associated with Mr. Holloway in selecting the fields to be dusted. An advisory committee consisting of representatives of the American Sugar-cane League, the University of Louisiana, and other individuals and organizations interested in the sugar-cane industry, will coöperate with the department in conducting the experiment.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

THE HALOGEN ACCEPTOR THEORY OF SENSITIVITY AND THE THIOANILIDES.[1]

By S. E. Sheppard and H. Hudson.

IT IS shown that thioanilides combine with silver halides to form relatively insoluble double compounds, the thioanilide behaving as a strong halogen acceptor, which greatly increases the sensitivity of visible decomposition. The double compound is not at all rapidly decomposed to silver sulphide, even in the presence of strong alkalies. No sensitizing for the latent image is produced under these conditions. If, however, the thioanilide is first hydrolyzed in the heat in strong alkaline solution, aniline is split off and sodium thioacetate formed, which does act as a sensitizer for the latent image. The thioanilides have no sensitizing effect but have some retarding action on development of the latent image analogous to that of soluble iodides. It appears from this that strong halogen accepting power in a substance incorporated in the silver halide grain is not sufficient in itself to induce sensitizing for the latent image.

THE THERMODYNAMIC POSSIBILITIES OF THE SILVER SULPHIDE BROMINE-ACCEPTOR HYPOTHESIS OF LATENT IMAGE FORMATION.[2]

By R. H. Lambert and E. P. Wightman.

ASSUMING, as claimed by Eggert and Noddack, that at least one silver bromide pair in the silver bromide crystal lattice is decomposed for each quantum of light energy absorbed; and, second, that the photochemical energy can supply the free energy of decomposition in the case of a light-sensitive substance like silver bromide; it has been found that the silver sulphide bromine-acceptor hypothesis of the latent image formation proposed by

* Communicated by the Director.

[1] Communication No. 308 from the Kodak Research Laboratories and published in *Phot. J.*, 67, 359, 1927.

[2] Communication No. 312 from the Kodak Research Laboratories and published in *J. Phys. Chem.*, 31, 1249, 1927.

Hickman is thermodynamically possible. It is further shown that the two specific series of reactions for arriving at a latent image, which he mentions as possibilities, are less likely to take place from a thermodynamic standpoint than some others which have been considered because one of his suggested intermediate reactions in each case has a very high positive free energy. The suggestion that silver sulphide may be decomposed photochemically and that silver bromide serves as the sulphur acceptor giving rise to sulphur bromide and silver is found to be thermodynamically sound, but would make the spectral sensitivity different from that of silver bromide. The free energy of formation of silver sulphide and of sulphur bromide have been calculated, the one from the electrochemical data of Noyes and Freed, the other from the work of Spring and Lacranies on the dissociation of sulphur bromide. These are respectively −6355 and −3040 calories.

LIGHT FILTERS, THEIR CHARACTERISTICS AND APPLICATIONS IN PHOTOGRAPHY.[8]

By L. A. Jones.

THE earlier sections of this paper deal with the fundamental laws of the reflection absorption and transmission of radiant energy by optically homogeneous media such as are used in the manufacture of photographic light filters, glass, gelatin, liquid solutions, etc. The application of these laws to the computation of filter characteristics is illustrated. This includes a consideration of the results due to surface reflection and of the variation in absorption as dependent upon concentration of the dye or the thickness of the absorbing layer. Methods of computing the absorption obtained by the superposition of two or more filters are illustrated. The theory of filter factor measurement is discussed, attention being called to the fundamental characteristics of photographic materials, the spectral distribution of energy in the illuminant, and the absorption characteristics of the filter upon which the value of multiplying factor of a filter depends. It is emphasized that the expression of filter factor without a statement of these conditions is meaningless.

Light filters for use with panchromatic materials are divided

[8] Communication No. 307 from the Kodak Research Laboratories, and published in *Trans. Soc. Mot. Pict. Eng.*, 11: No. 30, 135, 1927.

into two classes, (*a*) those used for obtaining orthochromatic reproduction of the brightness factor of color, and (*b*) those used for obtaining distortion (anorthochromatic) reproduction of the brightness factor. The theory of orthochromatic reproduction is treated briefly, it being shown that the absorbing characteristics of an orthochromatic filter depend upon the spectral sensitivity of the photographic material and the visibility of radiation. The spectrophotometric density curve of a perfect orthochromatic filter is computed. General rules are given for using contrast filters for the anorthochromatic reproduction of color. The relation between the absorption characteristics of light filters and the spectral reflection characteristics of colored objects which must exist for the enhancement or depression of a specified color on the brightness scale is discussed.

A PNEUMATIC FILM SQUEEGEE.[4]

By J. I. Crabtree and C. E. Ives.

THE most satisfactory method of removing excess moisture from motion picture film after washing is to impinge a blast of air on both sides of the film. Pneumatic squeegees accomplishing this are in general use on processing machines, but they have not been adopted by smaller laboratories using the rack and tank system owing to the non-adaptability of the conventional squeegee for the purpose. An apparatus is described for blowing the water from the film during transference from the film rack to the drying reel.

A special filter for removing dirt and oil from the air supply is also described.

MOTION PHOTOMICROGRAPHY WITH THE CINÉ-KODAK.[5]

By C. Tuttle.

FOR the use of the Ciné-Kodak for photomicrography, two auxiliary pieces of apparatus are desirable: (1) A view finder which can be used while pictures are being made with the micro-

[4] Communication No. 305 from the Kodak Research Laboratories, and published in *Trans. Soc. Mot. Pict. Eng.*, 11: No. 30, 270, 1927.

[5] Communication No. 304 from the Kodak Research Laboratories, and published in *Trans. Soc. Mot. Pict. Eng.*, 11: No. 30, 213, 1927.

scope. (2) A driving mechanism which will operate the camera at various taking rates from one picture in three minutes to two or three times normal speed.

The problems in optics, mechanics, and photography encountered in the design of such apparatus are discussed. The relation between magnification and resolution for the case of Ciné-Kodak pictures is of particular importance.

A number of examples of motion photomicrography are presented.

NOTES FROM THE U. S. BUREAU OF MINES.*

CARBON MONOXIDE IN TWO LARGE GARAGES.

By S. H. Katz and H. W. Frevert.

THE Government Fuel Yards at Washington, D. C., operated by the Bureau of Mines, maintain a large garage for motor trucks and cars used in distributing coal to the government buildings. The Bureau of Mines determined the carbon monoxide in the garage atmosphere over a period of three weeks in January, 1927. Records were also obtained in a large commercial garage in Pittsburgh, through most of February to May, 1927. Records were kept with the continuous recorder developed by the Bureau of Mines.

The maximum carbon monoxide noted was as high as 8.9 parts per ten thousand (p.p.t.t.) in the government garage, but the average for any working day did not exceed 1 p.p.t.t. In the corporation garage the maximum exceeded the recorder limits, 8.3 p.p.t.t. but such high concentrations were only momentary, the highest average for one hour being 4.3 p.p.t.t., which might cause headache in some employees, but the highest daily average was 1.64 p.p.t.t.

On the whole, conditions as to carbon monoxide content were not found to be very bad as regards possible effects on workmen, but in very severe weather when doors are kept more tightly closed, possibly worse conditions may be expected in large garages of the type tested.

A more complete report is being issued in *Industrial and Engineering Chemistry*.

IMPROVED PROCESS FOR LEACHING COPPER ORES.

A PROCESS for agglomerating fine material in leaching ores has been developed by metallurgists of the Southwest Experiment Station, that promises wide application in the treatment of copper and other ores. The slime and fine particles are caused to cohere together or adhere to the larger particles of the ore, so that fine ores hitherto regarded as impervious to leaching solutions can be

* Published by permission of the Director. Not subject to copyright.

made permeable. The method simply involves the mixing of dry crushed ore with moistening until the fine particles agglomerate, and then leaching in open heaps with a downward trickling solution. Open drainage must be maintained at the bottom and the solution must not be permitted to pool on the surface. This principle offers great possibilities for treatment of hundreds of millions of tons of low-grade tailings from copper concentrators carrying 0.2 to nearly 1 per cent. copper, also to large tonnages of ores that slime in crushing or require very fine grinding.

SEMI-ANNUAL MOTOR GASOLINE SURVEY.

By E. C. Lane, D. J. Condit, and C. S. Luce.

THE motor gasoline survey for June, 1927, is the sixteenth semi-annual survey of gasoline being marketed in representative cities of the United States. The results show that the gasoline being marketed this summer is slightly more volatile than that marketed a year ago. Comparison with surveys for previous years shows that refiners are tending more and more toward a standardized product.

The details will be found in Serial No. 2827.

THE FRANKLIN INSTITUTE.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 14, 1927.)

LIFE NON-RESIDENT.

PROF. VLADIMIR KARAPETOFF, Professor of Electrical Engineering, Cornell University, Ithaca, N. Y. For mailing: 520 East Buffalo Street, Ithaca, N. Y.

RESIDENT.

MR. ALBERT GLEDHILL, Chemist, Wilson-Martin Company. For mailing: 1534 Harrison Street, Philadelphia, Penna.

MR. C. M. JOHNSTON, Engineering and Railroad Contractor, 1537 Commercial Trust Building, Philadelphia, Penna.

DR. THOMAS M. SNYDER, Physician, 1521 Medical Arts Building, Philadelphia, Penna.

NON-RESIDENT.

MR. WILSON AULL, JR., Radio Engineer, Room 707–41 Park Row, New York City, N. Y.

MR. WARREN A. MARRISON, Laboratory Engineer, 463 West Street, New York City, N. Y.

MR. FRANK L. MORSE, President, Morse Chain Company, Ithaca, N. Y.

MR. EBENEZER T. TURNER, Librarian, Box 434, Ithaca, N. Y.

MR. FRED M. ZEDER, Engineer-Vice-president, Chrysler Corporation, Detroit, Mich.

STUDENT.

MR. ROBERT B. KLEINSCHMIDT, Student, 3224 North Carlisle Street, Philadelphia, Penna.

CONTRIBUTING.

Representing E. G. Budd Manufacturing Company:
MR. C. L. EKSERGIAN, 427 Laurel Road, Lansdowne, Penna.

CHANGES OF ADDRESS.

PROF. S. LAWRENCE BIGELOW, 1520 Hill Street, Ann Harbor, Mich.

MR. FRANCIS L. CRAMP, 6223 Greene Street, Germantown, Philadelphia, Penna.

MR. ROLAND B. DAY, 333 Judge Building, Salt Lake City, Utah.

MR. THOMAS H. DOUGHERTY, 1522 Locust Street, Philadelphia, Penna.

MR. WALTER F. GRAHAM, Technical Department, The Ohio Brass Company, Mansfield, Ohio.

MR. JOHN W. HORNSEY, Chemists Club, 52 East Forty-first Street, New York City, N. Y.
DR. ENOCH KARRER, 33 West Lowell Street, Akron, Ohio.
PROF. A. E. KENNELLY, Harvard University, Cambridge, Mass.
MR. L. B. LEWIS, Reading Company, Spring Garden Street Station, Philadelphia, Penna.
PROF. L. W. MCKEEHAN, Sloane Laboratory, Yale University, New Haven, Conn.
DR. RALPH MODJESKI, 1420 Walnut Street, Philadelphia, Penna.
MR. EDGAR B. NICHOLS, Victor Talking Machine Company, Camden, N. J.
MR. DONALD A. NIGHTINGALE, In care of Robinson and Bradley, 7 Kings Bench Walk, Temple, London, E. C. 4, England.
MR. CHARLES H. NORDHAUS, 4535 North Lincoln Street, Chicago, Ill.
MR. E. A. SMITH, Consulting Electrical Engineer, 735 Ninth Street, Secaucus, N. J.
MR. CHARLES A. STANWICK, 33 Beech Street, East Orange, N. J.
DR. W. F. G. SWANN, Bartol Research Laboratories of The Franklin Institute, 127 North Nineteenth Street, Philadelphia, Penna.
MR. C. H. VEEDER, 1 Elizabeth Street, Hartford, Conn.
DR. EDWARD L. ZIESEL, Laboratories, County Court House, Ventura, Calif.

NECROLOGY.

Mr. Alfred C. Harrison, Philadelphia, Penna.
Mr. Mitchell Harrison, Nokesville, Va.
Dr. Alexander C. Humphreys, Hoboken, N. J.
Mr. Paul Spencer, Philadelphia, Penna.
Dr. William H. Trueman, Germantown, Philadelphia, Penna.

MINUTE OF THE BOARD OF MANAGERS RELATIVE TO THE DEATH OF MR. ALFRED C. HARRISON. ADOPTED WEDNESDAY, SEPTEMBER 14, 1927.

THE Board of Managers of The Franklin Institute desires to express its sense of loss caused by the death of Alfred C. Harrison, and its sincere sympathy for the members of Mr. Harrison's family in their bereavement.

Mr. Harrison had been a member of The Franklin Institute since June, eighteen hundred and eighty-nine, and a member of the Board of Managers for thirty-two years. He was one whose advice was frequently sought and highly valued. He had shown a devoted interest in the affairs of the Institute and had proven himself a generously helpful supporter and friend. The Board of Managers deplores his death greatly.

The members of the Board who individually had the privilege of knowing Mr. Harrison intimately, had come to feel for him a high regard, supreme confidence in his integrity and his motives, and great respect for his judgment. They mourn in his death the loss of a personal friend as well as a leading member of The Franklin Institute.

The Board of Managers directs that this minute be spread upon its records, and that a copy of it be sent to the family of Mr. Harrison.

LIBRARY NOTES.

RECENT ADDITIONS.

ADHÉMAR, ROBERT D'.—Statique Cinématique. 1923.

APPEL, PAUL.—Les Éléments d'Analyse Mathématique. 1921.

BALLY, ÉMILE.—La Géométrie Générale Synthétique Moderne. 1922.

BARBER, EDWIN ATLEE.—Catalogue of Mexican Maiolica Belonging to Mrs. Robert W. DeForest, Exhibited by The Hispanic Society of America, February 18 to March 19, 1911. 1911.

BARBER, EDWIN ATLEE.—Hispano-Moresque Pottery in the Collection of The Hispanic Society of America. 1915.

BARBER, EDWIN ATLEE.—Mexican Maiolica in the Collection of The Hispanic Society of America. 1915.

BARBER, EDWIN ATLEE.—Spanish Glass in the Collection of The Hispanic Society of America. 1917.

BARBER, EDWIN ATLEE.—Spanish Maiolica in the Collection of The Hispanic Society of America. 1915.

BARBER, EDWIN ATLEE.—Spanish Porcelains and Terra Cotta in the Collection of The Hispanic Society of America. 1915.

BECQUEREL, JEAN.—Le Principe de Rélativité. 1922.

BLUM, ANTHONY.—Petroleum: Where and How to Find It. 1922.

BROWN, C. L. M.—The Conquest of the Air. 1927.

BYNE, ARTHUR, and STAPLEY, MILDRED.—Decorated Wooden Ceilings in Spain: A Collection of Photographs and Measured Drawings with Descriptive Text. 1920.

BYNE, ARTHUR, and STAPLEY, MILDRED.—Spanish Ironwork. 1915.

COOPER, F. J.—Textile Chemistry: An Introduction to the Chemistry of the Cotton Industry. No date.

EDWARDS, JUNIUS DAVID.—Aluminum-Bronze Powder and Aluminum Paint. 1927.

FARNSWORTH, PAUL V.—Industrial Mathematics Practically Applied. 1921.

FERRY, ERVIN S.—A Handbook of Physics Measurements. Volume II. First edition. 1918.

FRANKLIN, WILLIAM S., and MACNUTT, BARRY.—Lessons in Electricity and Magnetism. 1919.

FRANKLIN, WILLIAM S., and MACNUTT, BARRY.—Lessons in Heat. 1920.

FRANKLIN, WILLIAM S., and MACNUTT, BARRY.—Lessons in Mechanics. 1919.

FRIEND, J. NEWTON, Editor.—A Text-book of Inorganic Chemistry. Volume vii, Part I. 1924.

HAAG, J.—Les Mathématiques Spéciales. Tome II. 1921.

HAYWARD, CHARLES B.—How to Become a Wireless Operator. 1918.

HORNOR, H. A.—Spot and Arc Welding. 1920.

International Congress of Applied Mechanics.—Proceedings of the Second Congress at Zurich, 1926. 1927.

KEINATH, GEORG.—Elektrische Temperaturmessgeräte. 1923.

KLEOMEDES.—Die Kreisbewegung der Gestirne. Ostwald's Klassiker der exakten Wissenschaften Nr. 220. 1927.

LAMOUCHE, ANDRÉ.—La Methode Générale des Sciences. 1924.

LÉVY, PAUL.—Les Leçons d'Analyse Fonctionelle. 1922.

LOUIS, HENRY.—Mineral Valuation. 1923.

MALET, HENRI.—Étude Géométrique des Transformations Birationelles. 1921.

MANGIN, A., and TSCHIKOLEW, W.—Drei grundlegende und gemeinverständliche Arbeiten zur Scheinwerferfrage. Ostwald's Klassiker der exakten Wissenschaften Nr. 219. 1927.

Master Boiler Makers' Association.—Official Proceedings of the Eighteenth Annual Convention. 1927.

MULLIN, CHARLES E.—Acetate Silk and Its Dyes. 1927.

PETROW, REYNOLDS, SOMMERFELD, and MICHELL.—Hydrodynamische Theorie der Schmiermittelreibung. Ostwald's Klassiker der exakten Wissenschaften Nr. 218. 1927.

PICARD, ÉMILE.—Mélanges des Mathématiques et de Physique. 1924.

PRATT, JAMES A.—Elementary Machine Shop Practice. 1921.

Reichspatentamt 1877–1927.—Rückblick auf sein Werden und Wirken. 1927.

ROOT, RALPH E.—The Mathematics of Engineering. 1927.

SHELDON, H. HORTON, and Others.—Physics for Colleges. 1926.

SMALLWOOD, JULIAN C.—Mechanical Laboratory Methods. Second edition, 1918; third edition. 1922.

SOLEY, JOHN C.—Sources of Volcanic Energy. 1924.

STODOLA, A.—Steam and Gas Turbines. Authorized translation from the sixth German edition by Louis C. Loewenstein. Two volumes. 1927.

Tapestries and Carpets from the Palace of the Pardo, Woven at the Royal Manufactory of Madrid: Loaned by His Majesty The King of Spain for Exhibition by The Hispanic Society of America. 1917.

WAGGAMAN, WM. H., and EASTERWOOD, HENRY W.—Phosphoric Acid, Phosphates, and Phosphatic Fertilizers. 1927.

WALLACE, ERNEST L.—Machine Design. 1918.

WATKINS, ALFRED.—Photography: Its Principles and Applications. Third edition, revised. 1927.

WEBSTER, DAVID LOCKE, and Others.—General Physics for Colleges. 1923.

WEISS, JOHN MORRIS, and DOWNS, CHARLES RAYMOND.—The Technical Organization: Its Development and Administration. 1924.

ZSIGMONDY, RICHARD.—Kolloidchemie. Zweite, vermehrte, und zum Teil umgearbeitete Auflage. 1918.

BOOK REVIEWS.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report No. 262, Friction of Aviation Engines. By S. W. Sparrow and M. A. Thorne. 27 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

The first portion of this report discusses measurements of friction made in the altitude laboratory of the Bureau of Standards between 1920 and 1926 under research authorization of the National Advisory Committee for Aeronautics. These are discussed with reference to the influence of speed, barometric pressure, jacket-water temperature, and throttle opening upon the friction of aviation engines. It is concluded that: (1) Changes in friction due to

changes in the temperature of the air entering the engine are negligible. (2) Changes in friction which result from changes in atmospheric pressure are due primarily to changes in pumping loss. An approximate figure for the engines mentioned in this report is that the friction mean effective pressure decreases about one-tenth of a pound per square inch for each decrease of 1 centimetre of mercury in the barometric pressure. (3) The increase in friction resulting from a decrease in throttle opening is due to the change in pumping loss. For the engines mentioned in this report, the change in friction mean effective pressure which accompanies a change in manifold suction of 1 inch (2.54 centimetres) of mercury ranges from 0.20 pound per square inch obtained at an engine speed of 1200 revolutions per minute to 0.39 at 1800 revolutions per minute. (4) For the range of speeds covered in this report, namely, from 1000 to 2200 revolutions per minute, the friction mean effective pressure increases with speed, but ordinarily the percentage increase is less than the corresponding percentage increase in speed. At low engine speeds the friction mean effective pressure changes much less with change in speed and in some instances remains practically constant. (5) Friction depends upon the viscosity of the oil upon the cylinder walls, which in turn depends upon the temperature of the jacket water. (6) While theoretical considerations would lead one to expect an increase in friction with increase in compression ratio, the evidence at hand indicates that this effect is slight.

The second section of the report deals with measurements of the friction of a group of pistons differing from each other in a single respect, such as length, clearance, area of thrust face, location of thrust face, etc. Results obtained with each type of piston are discussed and attention is directed particularly to the fact that the friction chargeable to piston rings depends upon piston design as well as upon ring design. This is attributed to the effect of the rings upon the thickness and distribution of the oil film which in turn affects the friction of the piston to an extent which depends upon its design.

Report No. 263, Preliminary Flight Tests of the N.A.C.A. Roots Type Aircraft Engine Supercharger. By Arthur W. Gardiner and Elliott G. Reid. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

An investigation of the suitability of the N.A.C.A. Roots type aircraft engine supercharger to flight-operating conditions, as determined by the effects of the use of the supercharger upon engine operation and airplane performance, is described in this report.

The supercharger has been previously described in N.A.C.A. Technical Report No. 230; the results of laboratory tests are also given there. The compressor has a displacement of 0.51 cubic foot per revolution and weighs 88 pounds.

The selection of a suitable propeller and the provision of satisfactory intake ducts and adequate engine cooling were preliminary problems. The supercharger was first tested in a modified DH-4 airplane with a 5.4 compression ratio Liberty-12 engine. Two sets of drive gears which enabled the maintenance of sea-level pressure at the carburetor intake up to 12,000 and 20,000 feet were provided. The higher gear ratio supercharger was next tested in a DT-2 landplane which was later converted to a twin-float seaplane; the DT-2

also had a Liberty engine. Loads up to 2000 pounds were carried in the seaplane with normal and supercharged engines.

Attention was concentrated on the operation of the engine-supercharger unit and on the improvement of climbing ability; some information concerning high speeds at altitude was obtained.

The supercharger was found to be satisfactory under flight-operating conditions. Although two failures occurred during the tests, the causes of both were minor and have been eliminated. Careful examination of the engines revealed no detrimental effects which could be attributed to supercharging.

Marked improvements in climbing ability and high speeds at altitude were effected. It was also found that the load which could be carried to a given moderate or high altitude in a fixed time was considerably augmented. A slight sacrifice of low-altitude performance was necessitated, however, by the use of a fixed pitch propeller.

From a consideration of the very satisfactory flight performance of the Roots supercharger and of its inherent advantages, it is concluded that this type is particularly attractive for use in certain classes of commercial airplanes and in a number of military types.

Report No. 267, Drag of Wings with End Plates. By Paul E. Hemke. 13 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

In this report a formula for calculating the induced drag of multiplanes with end plates is derived. The frictional drag of the end plates is also calculated approximately. It is shown that the reduction of the induced drag, when end plates are used, is sufficiently large to increase the efficiency of the wing.

Comparisons are made of calculated and experimental results obtained in wind-tunnel tests with airfoils of various aspect ratios and end plates of various sizes. The agreement between calculated and experimental results is good.

Analysis of the experimental results shows that the shape and section of the end plates are important.

Report No. 268, Factors in the Design of Centrifugal Type Injection Valves for Oil Engines. By W. F. Joachim and E. G. Beardsley. 15 pages, illustrations, quarto. Washington, Government Printing Office, 1927. Price, ten cents.

This research was undertaken at the Langley Memorial Aeronautical Laboratory, in connection with a general study of the application of the fuel injection engine to aircraft. The purpose of the investigation was to determine the effect of four important factors in the design of a centrifugal type automatic injection valve on the penetration, general shape, and distribution of oil sprays.

The general method employed was to record the development of single sprays by means of special high-speed photographic apparatus capable of taking 25 consecutive pictures of the moving spray at a rate of 4000 per second. Investigations were made concerning the effects on spray characteristics, of the helix angle of helical grooves, the ratio of the cross-sectional area of the orifice to that of the grooves, the ratio of orifice length to diameter, and the position of the seat. The sprays were injected at 6000, 8000, and 10,000

pounds per square-inch pressure into air at atmospheric pressure and into nitrogen at 200, 400, and 600 pounds per square-inch pressure. Orifice diameters from 0.012 to 0.040 inch were investigated.

It was found that decreasing the pitch of the helical grooves and thus increasing the centrifugal force applied to the spray increased the spray cone angle considerably, although the percentage increase was much less in dense air than in the atmosphere. On the other hand, the spray penetration decreased with increase in the amount of centrifugal force applied. About twice as much spray volume per unit oil volume was obtained with a high centrifugal spray as with a non-centrifugal spray. The spray cone angle increased, and the spray volume to oil volume ratio and spray penetration decreased with increase in the ratio of orifice area to groove area. Maximum spray penetration was obtained with a ratio of orifice length to diameter of about 1.5. Slightly greater penetration was obtained with the seat directly before the orifice.

NOXIOUS GASES AND THE PRINCIPLES OF RESPIRATION INFLUENCING THEIR ACTION. By Yandell Henderson and Howard W. Haggard, Laboratory of Applied Physiology, Yale University. 220 pages, 8vo. New York, The Chemical Catalog Company, Inc., 1927. Price, $4.50.

Many are the substances like the "juice of curséd hebenon, the leprous distilment, whose effect holds such an enmity to the blood of man." Nature is prolific in things which delight our senses and benefit our bodies, but also in those which disgust and injure. The study of poisons has been actively pursued for a long time, but just as philosophers have never succeeded in agreeing upon basic definitions in ontology, toxicologists have never succeeded in agreeing upon what is a poison. In fact, any substance capable of being absorbed by the living organism may be a poison in certain dose, while substances of very active character if taken in very small dose may not only be without dangerous effects but even beneficial.

The standard manuals of toxicology limit themselves mostly to the substances that are introduced through the digestive system, although attention is given to a few gases which enter by the respiratory tract. Among these carbon monoxide receives the most attention.

The work in hand deals entirely with the gases that enter by the lungs and is also limited to those that are produced in the industrial field, omitting consideration of the so-called "war gases," the nature, effects and antidotes for which have been extensively treated in special manuals. The number of noxious gases encountered in the modern industries, either as definite products or as wastes incidental to other manufactures, is large. Many are highly toxic and their effects difficult to counteract or to treat. In addition to a comprehensive enumeration of these gases, the physiology and pathology of their actions are fully considered, so that the work is not only a valuable contribution to industrial hygiene, but a treatise on applied toxicology.

Almost the first third of the text is devoted to the physiologic and pathologic phenomena of absorption of the gases by the respiratory tract, including the reactions of the tract to the agents invading it. In this discussion many errors of inference from respiratory activity are pointed out. It has, indeed, been known for some time that small amounts of carbon dioxide are necessary

for the stimulation of lung action. As the authors say, "Breathing cannot be estimated by inspection." During rather active exercise, the amount of air inhaled may be much increased without injurious effect, but if a normal individual perfectly quiet should by voluntary act double the respiratory intake, serious results would soon follow. The digestive system of animals is fairly well prepared against poisonous materials inasmuch as the venous blood from the whole tract passes into the liver which acts as a filter, thus preventing the transmission of the poisonous material directly into the blood stream. This protection does not extend by any means to all substances, and when doses are large the liver may fail to deal with the amount present. The lungs have no such protection. The gases that are inhaled can enter directly into the blood stream. As with ordinary toxic substances, solid and liquid, we notice two very distinct effects of gases, the direct chemical action on the tissues and the action through absorption into the blood. We could classify, therefore, the gases as the ordinary poisons are classified, into corrosives, irritants and neurotics, but this is not satisfactory and the classification of this book is into asphyxiants, irritants and anesthetics. Gases can kill simply by exclusion, thus nitrogen and hydrogen are without particular effect upon the human tissues, but of course animals plunged into them without the presence of oxygen would perish simply by the loss of the life-giving element. Some instances of suffocation due, as far as could be ascertained, to a lowering of the oxygen content of the air in a ship's hold without the presence of any specific poisonous substance, were observed by the present reviewer in a ship which was discharging cargo. Several of the men working in the hold were rendered promptly unconscious on descending into it. Some were not rescued in time to save them. Those who recovered stated that no odor or irritant effect had been noted.

Necessarily carbon monoxide occupies a prominent place in this book. It has been for a long while a widespread cause of fatalities. Easily produced in the combustion of coal in our common furnaces and stoves, it was introduced less than half a century ago extensively into American homes through the distribution of water gas. The original illuminating gas contained but a small amount of it, and the not infrequent cases of asphyxiation from the practice of the inexperienced, especially the visitors from the rural districts of "blowing out the gas," were usually successfully treated. The introduction of water gas with its large proportion of carbon monoxide has caused an enormous increase of mortality, as the records of many American cities will show. A second and abundant source of this substance is automobile exhaust. Considerable space is given in the book to the sources of carbon monoxide, its effect in various degrees of concentration, its elimination from the body and its chemical pathology. The last group of gases considered in the work is that of the inorganic and organo-metallic substances. One of the most important is mercury. Although it has a high boiling-point, it vaporizes at comparatively low temperatures, slowly and minutely, but those constantly exposed to it suffer from very marked chronic poisoning. Phosphorus is another substance which has produced a very great deal of damage by being slightly volatile at ordinary temperatures. Many years ago mercuric methyl and mercuric ethyl which were prepared in a British laboratory resulted in the death of two of the assistants.

Poisoning by hydrogen arsenide is common, and hydrogen phosphide and hydrogen sulphide are fairly familiar, especially the latter, and very distinctly poisonous. Recently in connection with the automobile, the employment of lead tetrethyl has added a new risk to those exposed to the automobile exhaust. The last chapter of the book is a comprehensive discussion of the prevention and treatment of poisoning by these gases, emphasizing among other things the lack of legal protection against such, winding up with a discussion of the effect of noxious gases upon plants. The work is an extremely valuable and timely contribution to an important field in chemistry as applied to toxicology and hygiene.

HENRY LEFFMANN.

THERMODYNAMICS FOR STUDENTS OF CHEMISTRY. By C. N. Hinshelwood, M.A., Fellow and Tutor of Trinity College, Oxford. v–185 pages, 19 × 13 cm., cloth. New York, E. P. Dutton and Company. Price, $1.80.

The most obvious and readily visualized application of thermodynamics is to the heat-engine, about which that science originated and has been evolved into the definite form familiar to mechanical engineering students. Within comparatively recent years, chemical science has been enriched by the study of the physics of matter which undergoes chemical change in which energy relationships play a dominant part, and an adequate knowledge of thermodynamics as applied in that field has become essential to the study of physico-chemical phenomena.

The present volume sets forth in very understandable language the fundamental ideas of thermodynamics, its abstract general laws and how they are brought to bear upon the actual problems of physics and chemistry. Throughout the work, the interconnection between the laws of thermodynamics and the kinetic theory is kept in view, a feature which the author considers a marked addition to the deductive value of the discourse.

The first three chapters deal with the abstract laws of thermodynamics; the remainder of the book considers their applications to physico-chemical processes. The fourth chapter embraces an account of the derivation of the Gibbs-Helmholtz equation which applies to cyclic processes of all physical and chemical changes. Chapter five deals with applications of the isothermal reversible cycle. Chapter six is on entropy and thermodynamic functions. The seventh chapter is on the phase rule. Chapter eight considers the molecular interpretation of the second law of thermodyhamics and the physical meaning of entropy.

The work is an efficient text for students who seek a deductive presentation with an ample measure of explanation of this important subject.

LUCIEN E. PICOLET.

THE GENERAL THEORY OF THERMODYNAMICS, an introduction to the study of thermodynamics. x–104 pages, 20.5 × 14 cm., cloth. By J. E. Trevor, Ph.D., Professor of Thermodynamics in Cornell University. Boston, Ginn and Company. Price, $1.60.

The author's object in this presentation of theoretical thermodynamics is to place in the hands of students of physics and physical chemistry a text of deductive character in which adherence to mathematical rigor is a dominant feature. There are no applications, only the general principles of the subject

are considered, but if the reader experiences a lack of stimulation from its abstract character he is compensated by the unusually complete explanations of the processes and their mathematical relationships, much clarified, it may be mentioned, by a goodly number of well-chosen and finely executed illustrations. The treatment begins with the first and second laws of thermodynamics, the theorem of Carnot, the scale of absolute temperatures, the entropy law and finally the dissipation law and an important deduction from that law.

Logical consecutiveness and mathematical clarity are characteristic features of the book. LUCIEN E. PICOLET.

LES KAPOTIERS ET SUCCÉDANÉS, CULTURE ET EXPLOITATION. Par Félicien Michotte, Ingénieur E. C. P., Conseil-expert, Spécialiste en textiles et cultures coloniales. 83 pages, 19 × 15 cm., illustrations, paper. Paris, Société de Propagande Coloniale, 1927. Price, 15 francs.

Not very much information is to be found in readily available reference works on that unusually light-weight vegetable-fibre product known under the name of "kapok" which has many uses as a filling material for industrial and domestic purposes. This bulletin, which is one of a series issued by the Society with the object of promoting colonial resources, contains a generous collection of data on the varieties of kapok-producing plants, the localities of their cultivation, the applications of kapok and statistics of production. Unlike cotton, it has not proved so far applicable to the manufacture of woven fabrics, but it has many other uses where buoyancy and heat-insulating properties are desired and those who seek data on the sources of production, the present uses and possible application of that material will find this pamphlet highly informative. LUCIEN E. PICOLET.

PUBLICATIONS RECEIVED.

Optische Methoden der Chemie, von Fritz Weigert a. o. professor an der Universität Leipzig. 632 pages, illustrations, colored plate, 8vo. Leipzig, Akademische Verlagsgesellschaft m. b. H., 1927. Price, 38 marks.

Oildom, Its Treasures and Tragedies, essential and current truths about petroleum and the dependent oil and automotive industries, prepared primarily for motorists and investors, by Oscar H. Reinholt. 400 pages, illustrations, 8vo. Philadelphia, David McKay Co., 1927. Price, $4.

The Methods of Organic Chemistry. A Laboratory Manual, by C. W. Porter, T. D. Stewart and G. E. K. Branch, College of Chemistry, University of California. 311 pages, illustrations, 12mo. Boston, Ginn and Company, 1927. Price, $2.

Noxious Gases and the Principles of Respiration Influencing Their Action, by Yandell Henderson and Howard W. Haggard. 220 pages, illustrations, 8vo. New York, Chemical Catalog Company, Inc., 1927. Price, $4.50.

Institut International de Physique Solvay. Conductibilité électrique des métaux et problèmes connexes. Rapports et discussions du quatrieme conseil de physique tenu à Bruxelles du 24 au 29 Avril 1924 sous les auspices de l'Institut. 368 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1927. Price, 50 francs.

Applied Magnetism, by T. F. Wall, D.Sc., D.Eng. 262 pages, illustrations, 8vo. New York, D. Van Nostrand Company, Inc., 1927. Price, $8.

Elon College Bulletin. The Artelia Roney Duke Science Building. Dedicatory exercises and addresses. 46 pages, illustrations, narrow 16mo. Elon College, N. C., 1927.

Bulletin of the National Research Council No. 60. Industrial Research Laboratories of the United States, including consulting research laboratories. Third edition, revised and enlarged, compiled by Clarence J. West and Ervye L. Risher for Research Information Service. 153 pages, 8vo. Washington, National Research Council, 1927. Price, $1.

National Advisory Committee for Aeronautics: Technical Notes, No. 259, "Alclad," a New Corrosion-resistant Aluminum Product, by E. H. Dix, Jr. 13 pages, photographs. No. 260, Study of Open Jet Wind-tunnel Cones, by Fred. E. Weick. 15 pages, photographs. No. 261, Tension Experiments on Diaphragm Metals, by H. B. Henrickson. 14 pages, diagrams. No. 262, The Installation and Correction of Compasses in Airplanes, by M. F. Schoeffel. 17 pages, illustrations, four pamphlets, quarto. Washington, Committee, 1927.

U. S. Bureau of Standards: Scientific Papers, No. 550, Applications of the Algebraic Aberration Equations to Optical Design, by I. C. Gardner. 130 pages, illustrations, 8vo. No. 552, Transmission of Sound through Building Material, by V. L. Chrisler. 9 pages, 8vo. No. 554, Determination of Sulphur Trioxide in the Presence of Sulphur Dioxide, together with some analysis of commercial liquid sulphur dioxide, by J. R. Eckman. 9 pages, illustrations, plate, 8vo. Circular No. 319, Alphabetical Index and Numerical List of United States Government Master Specifications promulgated by the Federal Specifications Board. 17 pages, 8vo. Washington, Government Printing Office, 1927.

CURRENT TOPICS.

Flying Developments Show Need for More Ocean Weather Reports. (U. S. Department of Agriculture, Press Service.)—Toward the end of April, when preparations were started for trans-Atlantic flights by airplane, the number of ocean weather reports received by the Weather Bureau of the U. S. Department of Agriculture from ships plying the north Atlantic steamer lanes increased from four or five a day to twenty-five or thirty when interest in the flight projects was at its height. As a result, it was possible to keep the flyers well advised as to the winds, storms and fogs they would be likely to encounter.

This weather service, without which the hazards of the flights would have been enormously increased, was made possible largely by the voluntary coöperation of shipmasters and of the radio companies, which collected ocean weather information twice daily and delivered it to the Weather Bureau for charting and analysis. In future trans-Atlantic flying, such voluntary coöperation will hardly be as readily forthcoming, since the novelty of the enterprise will be gone and public interest in it less keen.

Officials of the Weather Bureau are accordingly considering what can be done to stimulate interest in ocean weather reports, which are valuable in forecasting weather conditions on land as well as in adding to the safety of flying and of navigation. It is their hope that shipmasters who have been sending out weather reports in the last two months will have formed the habit and will continue the work when the present flying season is over. Nevertheless, something more permanently dependable is essential.

One obstacle is the cost of taking observations and making them available by radio and telegraph to the weather forecasters. This cost has to be met by some one, even if it is voluntarily assumed and widely distributed as it was during the period in which weather service was maintained for the trans-Atlantic flyers. The Weather Bureau's funds do not suffice for payment of observer services and radio tolls from all ships.

That a more complete and extensive organization of ship service is necessary is shown by the fact that on some days while the flyers were waiting for favorable conditions the Weather Bureau did not get a single ship report from areas a thousand miles wide in the Atlantic. Even on May 18th, two days before Lindbergh made his successful flight, no report was received from any ship between longitude 40 west and the Irish coast. It was not until he had started that weather reports from ships became nearly adequate. When Chamberlin made his flight the amount of information coming in was more abundant than in any previous period and continued so even after his successful landing in Germany.

Although the cost of getting weather reports is a difficulty, perhaps a greater one is the fact that often there are no ships in areas where dangerous conditions exist. Moreover, when ships are warned of storm areas they avoid them. The hurricane that struck Florida last year, for example, was forecast by the Weather Bureau, and ships in the hurricane area were advised of its approach. They got out of the way so promptly that for twenty-four hours before the storm struck the coast not a single weather report was received from a ship in the hurricane area, for the good reason that none was there. Another difficulty is heavy competition for the use of Atlantic radio facilities. Ships on the regular traffic lanes in the Pacific much more commonly and regularly send weather reports than those on the New York to Europe routes in the Atlantic.

Apparently, moreover, the value of weather forecasts to Atlantic shipmasters is not a sufficient inducement to them to make regular weather reports, since most ocean liners are well able to cope with ordinary storm conditions. Nevertheless, information of big blows would be of value to ocean liners.

Eventually, when funds and facilities permit, the Weather Bureau hopes to get reports twice daily from all the ships in the Atlantic lanes. Such reports, supplemented by reports from land stations in this country, in Canada, in Greenland and Iceland, and also in Europe, would make possible the preparation of complete ocean weather charts and dependable forecasts every day.

It is easy for shipmasters to give the required information. They are asked merely to state the position of their vessel, the barometric pressure, the barometric change in the preceding two hours, the force and direction of the wind, the kind, quantity, and movement of clouds, the presence or absence of fog, and brief remarks on any unusual weather conditions that may prevail, such as squalls, storms, or heavy seas. Radio transmission is simplified by the use of a code.

Westward Course of Industry. (Department of the Interior, Memorandum for the Press.)—In January, 1908, the centre of industry in the United States was on the northern boundary of Indiana, about 110 miles east of Chicago. In January, 1918, it was still on the northern boundary of Indiana but had moved about 50 miles nearer to Chicago. In January, 1926, it had moved 25 miles to the southwest of its position in 1918 and was about 50 miles southeast of Chicago. The total movement in the 18 years from 1908 to 1926 was about 75 miles in a west by south direction. This slow movement of the centre of industry during a period when the capacity of prime movers in central stations and manufacturing plants increased about 140 per cent. indicates that industrial development in the United States is proceeding at about the same rate in all sections but a trifle more rapidly in the western and southern parts of the country.

These determinations of the centre of industry, which have been

made by the Geological Survey, are based on the capacity of steam engines, steam turbines, water wheels, and internal-combustion engines installed in manufacturing plants and in public-utility power plants. Twice the weight is given to the power equipment in public-utility power plants, as it is used twice as much as power equipment in manufacturing plants. Previous determinations of the centre of industry have been based on the installed capacity of prime movers in manufacturing plants only. It is believed that more representative results are obtained by using the capacity of power equipment in both manufacturing and public-utility plants.

The geographic centre of the United States is near the centre of the northern boundary of Kansas, and the centre of population is in Owen County, southwestern Indiana. The centre of industry of the United States in 1926 was therefore 640 miles east by north of the geographic centre and about 170 miles due north of the centre of population.

THE FRANKLIN INSTITUTE

OFFICERS FOR 1927

President	WM. C. L. EGLIN
Vice-presidents	HENRY HOWSON C. C. TUTWILER WALTON FORSTALL
Secretary	HOWARD MCCLENAHAN
Assistant Secretary and Librarian	ALFRED RIGLING
Treasurer	BENJAMIN FRANKLIN
Controller	WILLIAM F. JACKSON, JR.

Board of Managers

JAMES BARNES	CHARLES DAY	CHARLES PENROSE
GEORGE H. BENZON, JR.	ARTHUR W. GOODSPEED	JAMES S. ROGERS
CHARLES E. BONINE	CLARENCE A. HALL	GEORGE D. ROSENGARTEN
EDWARD G. BUDD	ALFRED C. HARRISON	E. H. SANBORN
FRANCIS T. CHAMBERS	NATHAN HAYWARD	HASELTINE SMITH
G. H. CLAMER	GEORGE A. HOADLEY	SAMUEL T. WAGNER
THEOBALD F. CLARK	ROBERT W. LESLEY	J. T. WALLIS
WALTON CLARK	MARSHALL S. MORGAN	WILLIAM C. WETHERILL

PRESS OF
J. B. LIPPINCOTT COMPANY
PHILADELPHIA